DOUBLE CROSS-GRAIN.

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(With Plate XIII and 11 text-figures.)

There is a certain amount of ambiguity in the meaning of the term cross-grain as applied to wood owing to it being used to describe conditions of grain which are similar in appearance though due to different causes.

The simplest use of the term is in its application to a plank sawn obliquely to the longitudinal axis of a straight grained log. A similar condition of the grain can be seen in planks, especially in the outer ones, which have been sawn from logs of considerable taper.

A more logical use of the term is in the description of planks sawn from a torse or spiral-grained log, for in this case it is impossible to saw a plank without cutting across the grain.

There is still a further type of cross-grain, seen in many timbers native to hot climates, which might be called interlocked or double cross-grain, the investigation of which forms the subject of the present paper.

This grain can often be recognised by a characteristic banded appearance on radial surfaces, due to differences in the reflection of light from a number of zones parallel to the longitudinal axis of the trunk. When such a wood is planed, it is at once evident that the grain in alternate zones is inclined in opposite directions.

This variation in the inclination of the grain can also be demonstrated by making successive tangential splits in a narrow stick sawn transversely off the end of a radial board, when it will be found that the inclination of the grain swings alternately to the left and right of the straight.

In the absence of any specific investigation, the simple spiral grain of torse wood suggested that the grain of these exotic timbers is of the nature of a double spiral, the inclination of the grain alternating with the growth of the tree between a left-handed and a right-handed spiral. It was on this supposition that Professor Groom based the explanation of the warping and twisting phenomena of the dipterocarpous wood called Yang (1).

In order to continue his work on the warping and twisting phenomena shown by these woods and to investigate their structure Professor Percy Groom secured through the kindness of Mr R. S. Pearson, Imperial Forest Economist, India, portions of the trunks, in the form of cylindrical drums several feet or more in length, of the undermentioned Indian trees. These Professor Groom entrusted to me to make this preliminary investigation into the true nature of this type of cross-grain:

Flacourtia Cataphracta Roxb.	Bixaceae.
Pentacme suavis D.C.	Dipterocarpaceae.
Shorea robusta Gaertn.	,,
Pterospermum acerifolium Willd.	Sterculiaceae.
Garuga pinnata Roxb.	Burseraceae.
Chloroxylon Swietenia D.C.	Meliaceae.
Cedrela Toona Roxb.	,,
Pterocarpus Marsupium Benth.	Leguminosae.
Ougenia dalbergioides Benth.	,,
Dalbergia Sissoo Roxb.	,,
,, *latifolia* Roxb.	,,
,, *Oliveri* Gamble.	,,
Xylia dolabriformis Benth.	,,
Hardwickia binata Roxb.	,,
Anogeissus latifolia Wall.	Combretaceae.
Schrebera swietenoides Roxb.	Oleaceae.
Gmelina arborea Linn.	Verbenaceae.
Mallotus philippinensis Muell.	Euphorbiaceae.
Holoptelea integrifolia Planch.	Ulmaceae.

Before I received the material each drum had been sawn up into a number of half-inch boards of which only two at the most were truly radial. In addition there was a transverse disc, a little over an inch thick, for each species, but there was nothing to indicate whether the disc and drum had been contiguous, or separated, in the log from which they had been sawn.

METHODS OF INVESTIGATION.

The methods of investigation into the course of the grain can be classified under two headings, namely: (1) Preliminary Investigations, and (2) Detailed Investigations. The former deal with the methods of attacking the problem, while the latter are concerned with the actual investigation.

Preliminary Investigations.

As the edges of the boards had not been trimmed off except in *Albizzia procera,* it was an easy matter to assemble the boards and examine the grain on the reconstructed drums.

The species could be separated into two groups according to the grain shown on the surface of the drums but it was impossible to say how far this grouping would hold good for complete trunks.

I. **Grain of uniform inclination.**

Garuga pinnata came under this heading with a left-handed spiral grain.

Albizzia procera, as far as could be judged, also came under this heading with a straight grain.

Calophyllum sp. (Poon). An examination of a six-foot beam suggested that Poon should be included in this group.

II. **Grain of variable inclination.**

On the surface of some sectors of a drum the grain might be straight, on others inclined as a right-handed or left-handed spiral and again on others the grain might have a sinuous or serpentine course. The general direction of the grain where it was serpentine was either parallel or inclined to the axis of the trunk. Unlike the other group, there was no transverse level where the grain was uniformly inclined around the circumference.

All the remaining eighteen species came into this group, differing from each other in the degree of inclination shown by the grain and in the length of the undulations where the grain was serpentine. The drums were too short to find the average length of the undulations in the different species. The shortest undulations seen measured between six inches and a foot in length.

Each species had next to be tested for the occurrence of cross-grain which could readily be demonstrated by taking a narrow stick sawn transversely off the end of a radial board and splitting it radially down the centre.

The fracture on the transverse surface under the edge of the splitting instrument will naturally be straight but the fracture on the transverse surface, the reverse to the one struck, will be sinuous, the departures from the straight conforming to the variations in the inclination of the grain since the plane of fracture follows the inclination of the grain.

A radial stick from each species was treated in this manner and direct

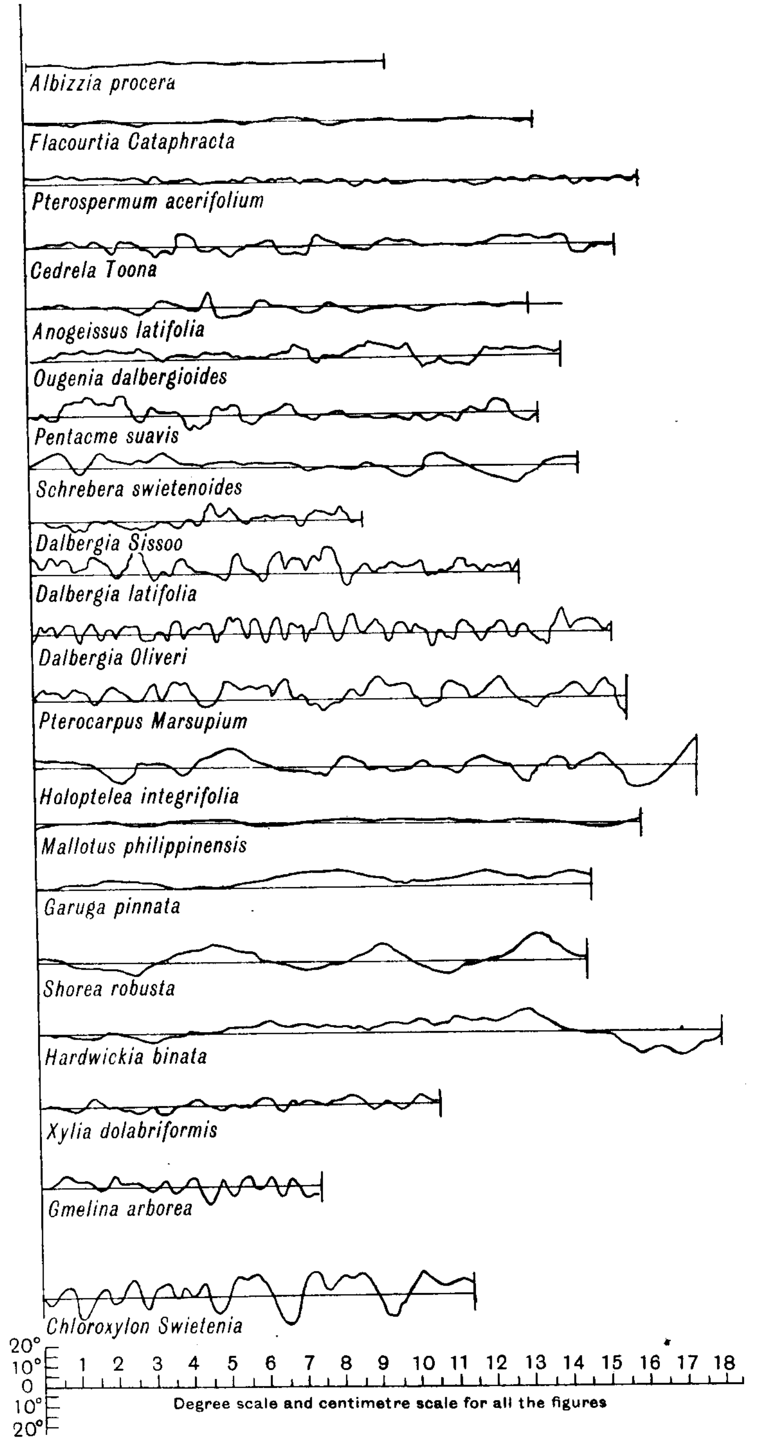

Fig. 1. Outline of a radial fracture for each species obtained from a stick an inch broad, sawn transversely off the end of a radial board.

tracings of the fractures obtained are reproduced in Fig. 1. An examination of the tracings shows that there are all types of gradation from the approximately straight grain of *Albizzia procera* to the uniform type of the double cross-grain characteristic of *Shorea robusta*.

The differences in the character of the cross-grain of the various species appear to be of a quantitative rather than of a qualitative nature, depending on the degree of regularity in the changes in the inclination of the grain, on the average radial distance between the successive right-handed and left-handed phases and on the a erage angle included between the maximum left-handed and right-handed inclinations of the grain.

The splitting of a radial stick provides a ready means of demonstrating changes of inclination in the grain for a very limited portion of the trunk, but in order to obtain a satisfactory insight into the variations in the inclination of the grain it is essential to know what the appearance of the grain would be like on the surface of the woody cylinder at successive intervals during the life of the tree.

The presence of clearly defined "growth-rings" greatly facilitated this investigation for, on the assumption that they delineated tissues produced at the same time, these rings supplied the necessary time unit without which it would have been impossible to proceed.

In order to obtain a general idea of the course of the grain in a drum use was made of these rings in the case of *Xylia dolabriformis* by splitting successive collars from off the disc at every fifth ring, and by careful planing of a radial board tangentially to the rings. In both cases the inclination of the grain was noted on the successively exposed surfaces.

It was not possible to make detailed records of the variations seen in the inclination of the grain, but the general impression obtained was that there were alternate right-handed and left-handed phases of inclination throughout the drum and that the conformation of the grain on the surface of the woody cylinder was at all times of the type already described under Group II, since, in the radial plane, the grain was often serpentine, its general direction alternating between left-handed and right-handed, and because around any ring in the transverse disc, the grain was never uniformly inclined although its inclination alternated with growth between wholly right-handed and wholly left-handed.

Before proceeding with the detailed method of investigation, a digression is necessary in criticism of the assumption that the rings of these Indian timbers are of the nature of growth-rings.

In dicotyledonous trees, native to temperate climates, the rings are defined by one or more of the following structural characters (see Groom (2)).

(1) Variation in the size of the vessels (Oak, Ash).
(2) Variation in the distribution of the vessels (Apple, Hawthorn).
(3) Decrease in the radial dimensions of one or more layers of wood elements (Sycamore, Poplar).
(4) Local decrease in the radial dimensions of the ray cells (Oak, Poplar).
(5) Local broadening of the rays (Oak, Beech).
(6) Presence of a more or less continuous sheet of parenchyma (Poplar).
(7) One or more layers of cells with darker contents.

Where the size and distribution of the vessels is uniform or nearly so and the remaining characters are ill-defined, it is often difficult to recognise a structural limit to the ring under the microscope, although rings can be recognised by the naked eye. This is the case with Boxwood and, to a lesser extent, with Pearwood.

Experience has shown that these rings are annual and are correlated with leaf fall and cessation of active growth before the cold weather sets in, and with the production of fresh foliage when conditions are again suitable for the assumption of growth in spring time.

All the Indian timbers examined in the course of this investigation showed concentric rings which, to the eye, were as well defined as those of many temperate climate trees.

In none of the species examined by the detailed method did the size or distribution of the vessels play any part in the definition of these rings, thus resembling the Willows, Poplars, and Horse Chestnut of this country.

The structural definition of the rings of these species, based on a limited number of sections, was as follows:

In *Chloroxylon Swietenia* the rings were very clearly defined by a layer or sheet of parenchyma two or three cells deep characterised by numerous simple pits.

In *Shorea robusta* the rings were defined by a sheet of parenchyma three or four cells deep. A slight tangential broadening of the rays was apparent where they passed through this sheet. Cysts or canals, probably of schizogenous origin, were of frequent occurrence in this layer.

The ring in *Hardwickia binata* was defined by a layer, three to six cells thick, consisting of parenchyma and of elongated narrow-lumened cells with brown, resinous looking contents. The walls of the elongated cells were thickly sprinkled with numerous fine pits.

In *Xylia dolabriformis* a layer, one or two cells deep, with darker contents, and apparently fibrous, bounded the rings.

The structural definitions of the rings in *Gmelina arborea* was much less distinct than in the other species although the rings themselves were apparent to the eye. An indistinct layer of parenchyma appeared to delineate the rings.

With regard to the relation between seasonal changes and the periods of growth of these trees, the following information was obtained from Brandis (3):

Chloroxylon Swietenia. Common in the deciduous forests of the Western Peninsula. Flowers March to April. Leaves renewed in May.

Shorea robusta. Never quite leafless. The young foliage appears in March with the flowers.

Hardwickia binata. ——

Xylia dolabriformis. Flowers while leafless, in March and April.

Gmelina arborea. Leaves shed from February to April. New foliage appears in May. Flowers from February to April, generally before the leaves are out.

Calophyllum sp. (Poon). Evergreen forests.

Similar seasonal changes are also recorded for the greater number of the remaining species.

The similarity, with regard to the structure of the rings and to the response to seasonal changes, between the Indian trees and the trees of temperate climate indicates that the rings shown in the Indian timbers are of the nature of growth-rings correlated with seasonal changes and lends support to their use as indices of contemporaneity.

Detailed Investigation.

The object of the method adopted was to find the inclination of the grain in every growth-ring of the trunk and to study how the inclination varied from ring to ring.

With the material to hand it was only possible to do this for one transverse and one radial plane of the drum, nevertheless, the data obtained were sufficient for forming a clear idea of the changes which the course of the grain underwent during the growth of the tree.

The rings were counted on the transverse disc of each species examined, and, to ensure correspondence in numbering along the different radii, the rings were followed completely round the disc. In places where the rings were indistinct, only the more prominent were traced round while the space between two such prominent rings was divided into a convenient number of equal subdivisions.

Where the growth of the tree did not show any great irregularities there would be little error in the contemporaneity of these "pseudo-growth rings" along the different radii of the disc.

After the rings had been counted and numbered, a number of sticks, usually eight in all and at an angle of 45 degrees to each other, were sawn radially out of the discs, care being taken to make the sides of the sticks as near as possible perpendicular to the surface of the disc. The sticks sawn from the disc constituted the transverse series for that species.

The longitudinal series were prepared by sawing a radial board of each species transversely into a number of sticks an inch in depth. The rings were counted on the corresponding transverse surfaces, differences of width and of tint ensuring correspondence in the numbering of the rings in the sticks of each longitudinal series.

Subsequent to the measuring of the width of the rings, the sticks of each transverse and longitudinal series were submitted to the following treatment.

By using a knife each stick was divided up into a number of thin slips by splitting parallel to the rings. So far as the width of the rings permitted a division was obtained between each ring, and in the broader rings as many as three or four splits were easily made. In order to prevent confusion the number of the ring was marked on each slip, a precaution necessitated by the large number of slips obtained from each stick.

The inclination of the grain was then measured on the outer tangential face of the slips and tabulated in conjunction with the width of the rings for each stick.

Lettering the outer face of a slip as in Fig. 2 the grain was traced by means of a lens and a fine needle from the top corner (B) or bottom corner (C) of the right-hand side BC, according to whether the inclination of the grain was right-handed or left-handed, to where it met the opposite side, CD or AB as the case might be, at the point X. By measuring XC or XB and the side BC with a micrometer screw, the angle of inclination of the grain (θ) to the straight could readily be calculated from the tangent.

The inclination of the grain was said to be right-handed and denoted by the sign "/" in the tables when it passed from the top right-hand corner toward the bottom left-hand corner; when it was inclined in the opposite direction it was said to be left-handed and denoted by the sign "\\". When the grain was parallel to the reference side *BC* it was called straight and was represented in the tables by the letter "*v*."

The inclination of the grain might equally well have been calculated with the left-hand side, *AD*, of the slips as a basis but for the sake of uniformity measurements were made from the right-hand side only.

The changes in the inclination of the grain along each stick were next plotted diagrammatically in the form of a curve. The rings were plotted along a horizontal line according to their width in centimetres to a scale of 2 to 1. To a scale of 1 mm. to a degree, the inclination of the grain at each ring was plotted in its correct position about the horizontal

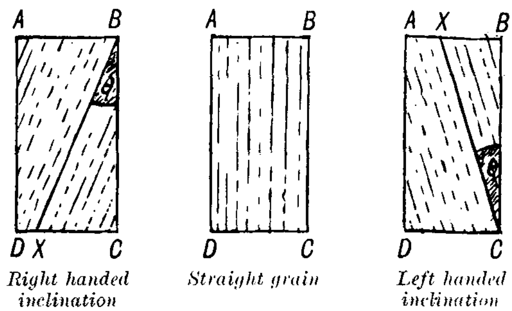

Fig. 2. Method determining the inclination of the grain.

line, degrees of right-handed inclination being plotted above the line, and degrees of left-handed inclination below the line. When the grain was straight the point was plotted in its correct position on the line itself.

On joining these points together a curve was obtained which showed at a glance both the inclination of the grain and the rate of change in the inclination of the grain at any ring.

In order to represent diagrammatically changes in the course of the grain in a radial plane the curves showing the changes in the inclination of the grain along the sticks of the longitudinal series were placed in sequence one above the other. The same procedure was adopted with the curves of the transverse series. On combining the results obtained from the examination of the transverse and longitudinal series of curves a comparatively clear mental picture was obtained in each species examined of the changes in the course of the grain during the life of the tree.

In order that the individual curves of a series should be more readily comparable among themselves the growth-rings were plotted for all the curves according to their width along a stick of intermediate length. In the longitudinal series this procedure produced no distortion of the curves since in all the species examined the width of the rings remained practically constant through the series, but in the transverse series, on the other hand, a distortion of some of the curves would be caused where the growth of the tree had been excentric. This distortion however will not affect the value of the curves for comparing changes in the inclination of the grain.

In order to test the reliability of the results obtained by this method of investigating the course of the grain, recourse was had to an elaboration of the method of radial fracture already described under the head of "Preliminary Investigations" as the most convenient method for demonstrating double cross-grain.

For checking the longitudinal series of curves, a radial board, if possible adjacent to the one which supplied the material from which the changes in the course of the grain in the longitudinal direction had been derived, was sawn transversely into a number of sticks an inch broad. For ease in subsequent comparison several of the more prominent rings were inked in on the corresponding transverse surfaces of the sticks. Each stick was then split radially, the direction of the split being made in the same sense in each stick. When the sticks were placed in sequence side by side a series of curved fractures was shown which, though not always identical in form, corresponded very closely with the longitudinal series of curves of the same species.

Prior to describing the course of the grain in the different species, it is advisable to mention the errors to which the method of investigation is subject and to estimate their probable effect on the results obtained.

The use made of the rings as an index of contemporaneity has already been discussed. The distinctness with which the individual rings could be followed round the discs and through the longitudinal series reduced errors in the numbering of the rings to a negligible minimum in all except the transverse series of *Gmelina arborea*.

In the actual measurement of the inclination of the grain on the slips repeated tests showed that errors from this source were not likely to have exceeded one degree.

Where the radial board had not been sawn parallel to the axis of the tree a uniform left-handed or right-handed bias in inclination would be given to the grain as a whole. In no case was there any appreciable inclination between the radial board and the axis of the trunk and in any case provided such inclination was not excessive, the comparative value of the curves would not be influenced since each stick would be equally affected.

The sticks of the transverse series were subject to a similar type of bias which was, however, of a two-fold origin; first to the possibility of the disc not being truly at right angles to the longitudinal axis and secondly to the sides of the sticks not being accurately perpendicular to the transverse surface.

The errors due to the first cause were considered to be negligible, since, as far as could be judged, a disc was never inclined at more than about five degrees to the transverse. The inclination between the sides of the different sticks of a transverse series varied within a range of three degrees at an outside estimation.

As in the longitudinal series errors due to these causes will not affect the comparative value of the curves so far as changes in inclination of the grain are concerned and need only be borne in mind when comparing the inclination of the grain at different points.

As to the sense in which various terms are used the words "Period length," "Amplitude" and "Phase" are employed with meanings analogous to those they possess when used in Physics for the description of wave motion.

The period length is the radial distance between the two maximum inclinations which delimited the period. Amplitude is the angle included between a maximum right-handed and left-handed inclination of the grain. As each period comprises a right-handed or left-handed swing of the grain which are only rarely of equal amount, the average of the two swings is taken as the amplitude of the period. It was on this basis that the ratio of period length to amplitude was worked out.

SHOREA ROBUSTA.

The data regarding the width of the growth-rings and the inclination of the grain at the various rings, from which the two series of curves (Figs. 3 and 4) were constructed are tabulated for the sticks of the transverse and longitudinal series in Tables I and II respectively.

Although in both series the rings were counted from the centre, the numbering of the rings in the two series does not correspond, there being fewer rings in the longitudinal series. This discrepancy is due to two

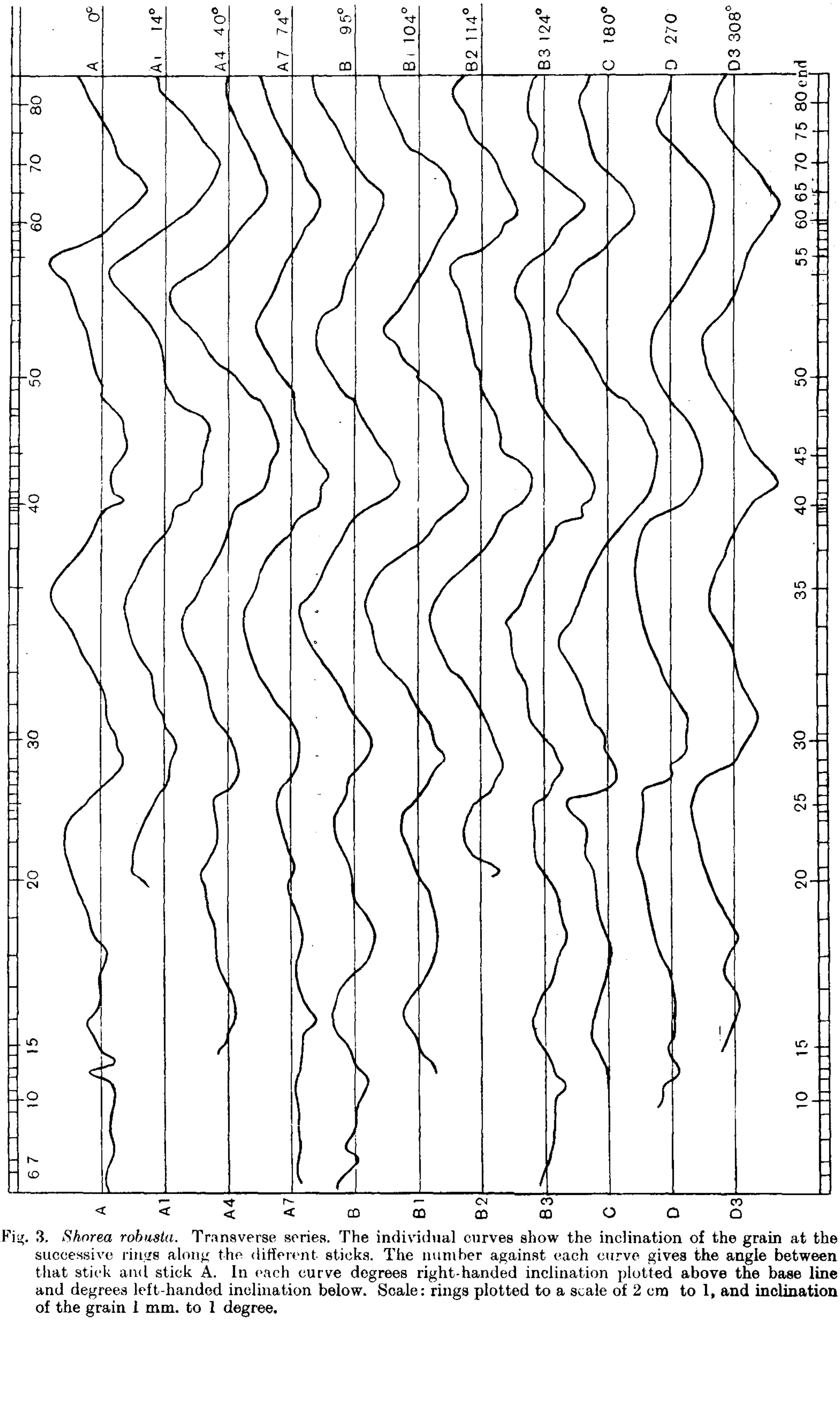

Fig. 3. *Shorea robusta.* Transverse series. The individual curves show the inclination of the grain at the successive rings along the different sticks. The number against each curve gives the angle between that stick and stick A. In each curve degrees right-handed inclination plotted above the base line and degrees left-handed inclination below. Scale: rings plotted to a scale of 2 cm to 1, and inclination of the grain 1 mm. to 1 degree.

Table I. *Shorea robusta*. Transverse series.

The first column of each stick gives distance of each ring in centimetres from the centre, and the second column inclinations of the grain in degrees in the different rings. Where the rings were broad three readings could be taken at the beginning, middle and end of the ring. Straight grain denoted by "*v*," right-handed inclination by "/" and left-handed inclination by "\."

No. of ring	A				A 1				A 4				A 7				B				B 1			
Centre	0 cms.		—		0 cms.	0			0 cms.		.		0 cms.		.		0 cms.		.		0 cms.			
1	.		—		.	.			.		.		.		.		.		.		.			
2	.		—		.	.			.		.		.		.		.		.		.			
3	.		*v*		.	.			.		.		.		.		.		.		.			
4	.		3 \		.	.			.		.		.		.		.		.		.			
5	1·10		1½\		.	.			.		.		1·80		3 \		2·00	6 /	6 /	.	.			
6	1·30		2½\		.	.			.		.		2·10		2 \		2·28	1½/	1 /	.	.			
7	1·80		4 \		.	.			.		.		2·60		3 \		2·50	½\	3 /	.	.			
8	2·15		3 \		.	.			.		.		2·90		2 \		2·85	½/	½\	.	.			
9	2·25		4 \		.	.			.		.		3·05		2½\		3·25	½\	.	.	.			
10	2·45		4½\		.	.			.		.		3·25		1½\		3·45	1½\	.	.	.			
11	2·60	.	3 \	.	.	.			.		.		3·50		.		3·60	4 \	.	.	.		.	
12	2·85	*v*	4 /	.	.	.			.		.		3·60		2½\		3·80	3½\	.	.	3·25		5½\	
13	3·30	3 \	4½\	1½\	.	.			.		.		3·70		.		3·95	*v*	.	.	3·45		4 \	
14	3·95	.	*v*	.	4·15	.			.	.	.	3 /	3·80		.		4·15	1½/	.	.	3·60		*v*	
15	4·20	.	2½/	4 /	4·35	.			4·45	*v*	*v*	1½\	3·90	3½\	3½\	7½\	4·30	2½/	6 /	.	3·75		1 /	4 /
16	4·60	.	*v*	.	4·65	.			5·10	2 \	2 \	*v*	4·65	7 \	4 \	*v*	4·70	.	6 /	5 /	4·10		4 /	½/
17	5·00	.	*v*	.	4·80	.			5·65	.	2½	.	5·15	.	.	2 \	5·18	.	*v*	4½\	4·55		3½\	5 \
18	5·19	1½\	2½/	2½/	5·15	.			5·85	3 /	3½/	4 /	5·75	.	4 \	2½\	5·70	.	6½\	5½\	5·15		6½\	6 \
19	5·90	.	6 /	.	5·90	.			6·45	6 /	6½/	7½/	6·35	.	*v*	*v*	6·30	.	*v*	½/	5·70		4 \	2 \
20	6·45	.	9 /	.	6·55	6½/	10 /	.	7·20	8½/	—	7½/	6·95	*v*	1 \	1 \	6·90	.	1 /	1 /	6·20		*v*	½/
21	6·60		—		6·90	9½/	9½/	.	7·80	5½/	5 /	3 /	7·60	1 \	*v*	.	7·10	.	2½/	4 /	6·82		1½/	
22	6·85		11 /		7·40		7 /		8·30		3 /		7·95	.	.	.	7·50		6 /		7·05		5 /	
23	7·25		8½/		7·55		.		8·40		.		7·98		3 /		7·85		6 /		7·20		.	
24	7·35		4 /		7·62		3½/		8·50		.		8·02		.		8·00		.		7·26		3 /	
25	7·60		3 /		7·80		2½/		8·60		4 /		8·05		4 /		8·10		2½/		7·30		*v*	
26	7·70		*v*		7·90		*v*		8·70		*v*		8·15		3 /		8·25		.		7·48		2 \	
27	8·10		4 \		8·30		2 \		8·95		2½\		8·25		*v*		8·40	.	.	1½/	7·74		4 \	
28	8·75		7 \		8·40		2 \		9·05	3½\	3½\	3 \	8·45		2 \		8·60	.	.	2½\	7·90		6 \	8½\
29	9·05		5½\		9·00	3 \	4½\		9·65		2½\		8·75		2½\		8·82	4 \	.	.	8·42		6 \	
30	9·30		5 \		9·50		3½\		10·15		*v*		8·95		2½\		9·10	.	5½\	.	8·68		5 \	
31	9·40	3 \	2 \	2 \	9·70	1 \	*v*	2 /	10·25	1 /	4 /	4½/	9·10		*v*		9·20	.	1 \	1½/	8·80		4 \	*v*
32	9·95	2 \	*v*	2 /	10·20	2½/	3 /	3 /	10·90	5 /	6 /	6½/	9·65		8 /		9·65	.	4 /	6 /	9·20		3 /	7 /
33	10·45	3½/	6½/	8½/	10·70	6 /	9 /	11/	11·55	8 /	12 /	14 /	10·25		12½/		10·15	.	13 /	16 /	9·65		13 /	13½/
34	11·10	11½/	15 /	.	11·45	11 /	12 /	11/	12·40	.	12 /	9 /	11·05		14 /	11 /	10·90	.	17 /	12½/	10·50		16 /	15 /
35	11·75	14 /	9½/	.	12·00	.	7 /	5 /	13·00	8 /	4 /	2½/	11·70		9½/		11·50	.	9 /	6 /	11·04		10 /	3½/
36	12·25	4½/	3 /	.	12·70		*v*	2 \	13·65		*v*		11·95		*v*		12·10	.	3 /	2 /	11·60	.	*v*	5½\
37	12·60	.	.	.	13·00		.		13·95		.		12·26		2 \		12·52	.	.	.	12·10	.	7 \	.
38	12·64	.	*v*	.	13·08		3 \		13·98		2 \		12·34	.	.	.	12·68	.	3 \	.	12·28	10\	.	.
39	12·67	.	.	.	13·16		.		14·01		.		12·40	9 \	.	.	12·71	.	.	.	12·32		.	
40	12·70	.	7 \	.	13·25		8 \		14·05		6 \		12·45	.	9½\	.	12·79	.	8 \	.	12·40		14½\	

41	12·90		3½\		13·30		8½\		14·10	.	.	.	12·55		.		12·90	.	10½\	.	12·46		.	
42	13·00		3½\		13·40		12 \		14·20	.	12½\	.	12·65	.	9½\	.	13·00	.	14 \	.	12·53		16 \	
43	13·15		3 \		13·50		12 \		14·35	.	.	.	12·75		12 \		13·20	.	13 \	.	12·60		14 \	
44	13·40		6½\		13·70		12½\		14·50	.	13½\	.	12·90		.		13·36	.	12 \	.	12·85		11½\	
45	13·55		8 \		13·90		12½\		14·55	.	16 \	.	13·00		6½\		13·60	.	9 \	.	13·15		10 \	
46	13·75		7½\		14·00		14 \		14·60	.	.	.	13·10		4½\		13·70	.	5 \	2½\	13·28		.	
47	14·05	6½\	5 \	2½\	14·20	12½\	8 \	.	14·70	.	.	.	13·50		1½\		14·20	.	.		13·36		8 \	
48	14·55	.	1 \	v	14·70	3 \	3 \	.	14·90	.	10 \	.	13·60		.		14·30	.	½\	2 /	13·82		8 \	6 \
49	14·95	.	v	.	15·05		v		15·10	.	5 \	.	13·85		v		14·60	.	2 /	.	14·00		3½\	v
50	15·15	2 /	3 /	3½/	15·15		v		15·30	v	4½/	.	14·00	4 /	.	8 /	14·80	.	6 /	6 /	14·43	v	5 /	6 /
51	15·95		4½/		15·30		3 /		15·60	.	10 /	.	14·55		11 /		15·35		10½/	12 /	15·20		9 /	
52	16·25		8 /		16·15		8½/		15·85		17 /		14·90		9 /		15·70		11½/	11½/	15·48		7 /	
53	16·45		10 /		16·55		15 /		16·05		18 /		15·20		4 /		15·95		9 /	6 /	15·70		2 /	
54	16·75		16½/		16·85		17 /		16·40		7 /		15·80		2½/		16·40		.	3 /	15·95		2 \	
55	17·05		13½/		17·20		11½/		16·75		3 /		16·20		v		16·70		1 /		16·05		4½\	
56	17·15		6 /		17·35		7½/		17·05		v		16·35		.		16·80		.		16·18		.	
57	17·30		v		17·50		3½/		17·25		2 \		16·50		3½\		16·95		2½\		16·28		7 \	
58	17·40		2 \		17·95		v		17·45		4 \		16·65		4 \		17·10		.		16·36		9 \	
59	17·60		3½\		18·05		2 \		17·55		.		16·80		.		17·20		.		16·46		.	
60	17·80		6 \		18·20		5½\		17·65		7 \		16·90		7 \		17·25		6½\		16·56		11½\	
61	17·86		.		.		.		.		.		.		.		.		.		.		.	
62	17·92		10 \		.		.		.		.		.		.		.		.		.		.	
63	17·98		.		.		.		.		.		.		.		.		.		.		.	
64	18·04		.		.		.		.		.		.		.		.		.		.		.	
65	18·10		14½\		18·50		13½\		18·05		12½\		17·45		8 \		17·70		8 \		17·00		10 \	
66	18·15		.		.		.		.		.		.		.		.		.		.		.	
67	18·20		.		.		.		.		.		.		.		.		.		.		.	
68	18·25		11 \		.		.		.		.		.		4 \		.		2½\		.		9 \	
69	18·30		.		.		.		.		.		.		.		.		.		.		.	
70	18·35		6 \		18·90		17 \		18·60		8 \		17·95		3 \		18·15		v		17·50		3 \	
71	18·42		.		.		.		.		.		.		.		.		.		.		.	
72	18·49		4½\		.		.		.		.		.		.		.		.		.		.	
73	18·56		.		.		.		.		.		.		v		.		.		.		4½/	
74	18·63		.		.		.		.		.		.		.		.		.		.		.	
75	18·70		2½\		19·40		9½\		19·15		3½\		18·50		3½/		18·65		6 /		17·95		5½/	
76	18·79		.		.		.		.		.		.		.		.		.		.		.	
77	18·88		.		.		.		.		.		.		.		.		.		.		.	
78	18·97		v		.		.		.		.		.		.		.		9 /		.		.	
79	19·04		.		.		.		.		.		.		.		.		.		.		.	
80	19·15		2 /		19·95		2½\		19·70		v		19·20		7½/		19·10		12 /		18·40		10½/	
End	19·80	.	5 /	7½/	20·45	2 /	2½/	.	20·70	.	v	v	19·70	.	.	10 /	19·55	.	.	13½	18·80	.	.	12½/

Table I (*continued*).

No. of ring	B 2				B 3				C				C 4		D		D 3	
Centre	0 cms.				0 cms.				0 cms.				0 cms.		0 cms.		0 cms.	
– 1	.				.				.				—	.	.		.	
2	.				.				.				—	.	.		.	
3	.				.				.				·65	.	.		.	
4	.				1·15		.		.				·75	.	.		.	
5	.				1·75		2 /		.				1·00	2 /	.		.	
6	.				1·95		*v*		.				1·15	4½/	.		.	
7	.				2·15		2 \		1·60		.		1·30	4 /	.		.	
8	.				2·40		2½\		1·85		.		1·40	2 /	.		.	
9	.				2·55	.	3 \	.	2·00		*v*		1·60	6 /	.	4 /	.	
10	.				3·00	3 \	3½\	.	2·45		*v*		2·00	4 /	1·90	2½/	.	
11	.				3·55		7 \		3·10		*v*		2·10	*v*	2·10	2½/	.	.
12	.				3·68		3½\		3·30		*v*		2·30	3 \	2·80	2½\	.	.
13	.				3·80		2½\		3·45		1 /		2·50	2 \	3·20	1 \	.	.
14	.				3·95		*v*		3·60		3 /		2·70	1 \	3·55	1 /	3·90	4 /
15	.				4·08		3 /		3·70		5 /		2·85	*v*	3·80	*v*	4·40	*v*
16	.				4·20		2 /		4·00		3 /		3·00	*v*	3·95	1 \	4·60	2 \
17	.				4·60	*v*	3½\	.	4·30		*v*		3·25	*v*	4·20	1 /	4·90	3 /
18	.				5·18	4½\	7½\	.	4·50		*v*		3·50	8 /	4·40	5 /	5·25	1½\
19	.	.	.	5½\	5·80	5½\	5 \	.	4·75		3 /		3·75	10 /	4·75	7½/	5·95	5 /
20	6·50	.	3 \	*v*	6·30	.	1 \	*v*	4·90		3½/		4·00	13 /	5·10	9 /	6·50	8 /
21	7·10		2½/	3½/	6·90	2½/	2½/	2½/	5·30		6½/		4·25	10 /	5·45	10½/	7·00	10 /
22	7·45		.		7·28		2½/		5·50		6 /		4·50	10 /	5·80	.	7·25	12 /
23	7·52		4 /		7·35		.		5·56		.		4·56	.	5·85	.	7·30	13 /
24	7·62		.		7·42	3½/	.	.	5·62		.		4·62	.	5·90	8½/	7·35	9½/
25	7·70		*v*		7·48		*v*		5·69		13 /		4·68	3 /	5·95	—	7·40	.
26	7·77		3½\		7·54	2 \	2 \	.	5·75		*v*		4·75	*v*	6·00	8½/	7·45	.
27	8·20		4 \		7·96		4 \		6·20		3 \		5·10	2 \	6·20	*v*	7·52	9½/
28	8·35		7 \		8·13	5½\	5½\	4½\	6·30		2½\		5·20	4 \	6·30	*v*	7·60	*v*
29	8·80		5½\		8·60		3 \		6·70		*v*		5·60	6½\	6·50	5 \	7·90	3 \
30	9·09		4 \		8·90		*v*		7·05		*v*		5·80	5½\	6·65	5 \	8·20	6 \
31	9·16		*v*		9·00		4½/		7·15		5 /		5·90	*v*	6·70	6 \	8·30	8 \
32	9·60		4 /	6½/	9·50		5 /		7·55		7½/		6·20	5½/	6·95	*v*	8·60	3½\
33	10·00	9 /	12½/	.	9·90	8½/	10 /	10/	7·95	—	14 /	14/	6·60	13 /	7·30	6 /	8·95	*v*
34	10·90	16 /	15 /	.	10·85	11½/	8 /	5½/	8·60	10½/	9½/	—	7·10	12½/	7·80	9½/	9·50	7½/
35	11·50	11 /	5 /	.	11·60	4 /	2 /	*v*	9·20		4 /		7·45	9 /	8·15	11 /	9·85	4½/
36	12·15	1½\	3½\	5 \	12·25	2 \	4 \	4 \	9·80		2½\		7·75	4 /	8·25	.	10·20	*v*
37	12·62		6 \		12·75		13 \		10·20		7½\		7·90	.	8·30	5½/	10·50	3 \
38	12·70		.		12·85		.		10·25		—		7·95	*v*	8·38	.	10·58	—
39	12·80		.		12·95		12 \		10·30		—		8·00	.	8·46	*v*	10·66	5 \
40	12·85		12½\		13·05		14½\		10·35		12 \		8·05	5 \	8·55	5 \	10·75	7 \

41	12·95		.		13·20		16 \		10·45	.	8·10	.	8·65	.	10·80	.
42	13·08		16 \		13·30		16 \		10·55	14½\	8·20	.	8·70	.	10·85	14 \
43	13·20		16 \		13·45		14½\		10·70	.	8·25	9 \	8·80	.	10·90	.
44	13·45		12½\		13·65		12 \		10·80	.	8·40	.	8·90	10 \	11·00	.
45	13·70		7 \		13·90		10 \		10·85	15½\	8·50	11 \	9·05	.	11·10	6 \
46	13·90		6 \		14·05		5½\		10·90	.	8·55	.	9·25	.	11·20	3 \
47	14·05		4 \		14·15		1 \		11·05	10½\	8·65	3 \	9·30	4 \	11·50	v
48	14·45		2 \		14·55	v	2 /	.	11·25	.	8·85	v	9·70	v	11·60	3 /
49	14·85		v		14·90	.	2 /	.	11·42	v	9·00	6 /	10·00	3½/	11·85	6 /
50	15·00	v	2½/	3 /	15·05	3 /	4 /	.	11·50	5 /	9·15	9 /	10·15	6 /	12·00	9 /
51	15·55		6 /		15·60		4 /		12·05	11 /	9·65	14 /	10·65	.	12·50	9 /
52	15·90		7½/		15·95		6 /		12·45	15½/	9·85	12½/	11·00	2 /	13·00	2 /
53	16·15		10½/		16·20		9 /		12·80	12 /	10·20	6½/	11·40	4 \	13·40	1 \
54	16·38		5½/		16·43		5 /		13·00	9½/	10·80	v	11·85	.	13·85	3 \
55	16·48		2 \		16·58		v		13·30	2½/	11·15	4 \	12·25	.	14·10	4 \
56	16·55		5 \		16·68		3 \		13·55	v	11·35	6½\	12·40	.	14·25	6 \
57	16·65		6½\		16·80		5 \		13·70	2 \	11·60	8 \	12·50	.	14·40	8 \
58	16·78		—		16·90		6 \		14·25	6 \	11·80	11 \	12·70	13 \	14·60	10 \
59	16·84	6½\	—		16·98		.		14·35	.	12·00	13 \	12·85	.	14·70	.
60	16·90	.	11 \	.	17·08		10 \		14·45	8 \	12·15	12 \	12·95	18½\	14·80	12 \
61	.		.		.		.		.	.	.	.	.	.	.	.
62	.		.		.		13 \		.	.	.	.	.	.	.	4½\
63	.		.		.		.		.	.	.	.	.	.	.	.
64	.		.		.		.		.	.	.	.	.	.	.	.
65	17·30		8½\		17·43		8½\		14·95	6 \	12·90	9 \	13·50	12½\	15·15	11½\
66	.		.		.		.		.	.	.	.	.	.	.	.
67	.		.		.		.		.	.	.	.	.	.	.	.
68	.		6 \		.		.		.	.	.	.	.	.	.	.
69	.		.		.		.		.	.	.	.	.	.	.	.
70	17·68		4 \		17·65		4 \		15·35	4 /	13·55	v	13·85	5 \	15·40	4½\
71	.		.		.		.		.	.	.	.	.	.	.	.
72	.		.		.		2 \		.	.	.	.	.	.	.	.
73	.		v		.		.		.	.	.	.	.	.	.	.
74	.		.		.		.		.	.	.	.	.	.	.	.
75	18·10		4 /		18·00		2½		15·80	6½/	.	5½/	14·30	4½/	15·60	4 /
76	.		.		.		.		.	.	.	.	.	.	.	.
77	.		5½/		.		5 /		.	.	.	.	.	.	.	.
78	.		.		.		.		.	.	.	.	.	.	.	.
79	.		.		.		.		.	.	.	.	.	.	.	.
80	18·58		9 /		18·38		5 /		16·00	9 /	14·55	8	14·60	1½/	15·85	6 /
End	18·90	.	.	5 /	18·75	.	.	3 /	16·50	6 /	15·15	3 /	15·10	v	16·30	3 /

Table II. *Shorea robusta.* Longitudinal series.

The first column of each stick gives distance of each ring in centimetres from the centre, and the second column inclinations of the grain in degrees in the different rings. Where the rings were broad three readings could be taken, at the beginning, middle and end of the ring. Straight grain denoted by "*v*," right-handed inclination by "/" and left-handed inclination by "\."

No. of ring	No. 1		No. 2		No. 3		No. 4		No. 5		No. 6	
	cms.		cms.		cms.		cms.		cms.		cms.	
10	0	.	1·60	4½\ 6 \ .	1·60	3\ 4½\ .	1·40	*v* 1½\ .	1·30	*v* *v* .	1·20	*v* 4 \
11	.	6 \ 7½\	.	5 \	.	3 \	.	2 \	.	3½\	.	2 \
12	.	4 \	.	1 \	.	1 \	.	2½\	.	*v*	.	*v*
13	.	2½\	.	*v*	.	*v*	.	2½\	.	*v*	.	1 \
14	.	1 \	.	*v*	.	*v*	.	1½\	.	2½\	.	3 \
15	1·75	4½\ 2½\ 2 \	3·00	1 \	3·00	*v*	2·90	*v*	2·80	2½\	2·70	3 \
16	.	3 \	.	*v*	.	1 /	.	1 \	.	2½\	.	3 \
17	.	1 /	.	1 /	.	1½\	.	2 \	.	1 \	.	*v*
18	.	2 /	.	*v*	.	1½\	.	*v*	.	*v*	.	2 /
19	.	*v*	.	4 \	.	4 \	.	*v*	.	2½\	.	5½/
20	4·40	4½\	5·50		5·50		5·30		5·20		5·20	
21	.	7 \	.	6½\	.	4 \	.	3 \	.	*v*	.	*v*
22	.	3½\	.	*v*	.	2½/	.	3 /	.	2 /	.	3 \
23	.	*v*	.	6½/	.	6 /	.	3½/	.	*v*	.	4 \
24	.	4 /	.	7½/	.	6 /	.	2½/	.	4½\	.	9 \
25	6·45	. 6 / .	7·60	7½/	7·60	6½/	7·60	3 /	7·60	*v*	7·70	3½\
26	.	8 /	.	5½/	.	2 /	.	3 \	.	2 /	.	*v*
27	.	*v*	.	1½\	.	4½\	.	7 \	.	4 \	.	3½\
28	.	4½\	.	7 \	.	7½\	.	9½\	.	8 \	.	6 \
29	.	10½\	.	12 \	.	10 \	.	14 \	.	12 \	.	13 \
30	8·90	17 \	10·10	17½\	10·10	15½\	10·00	18 \	10·00	15 \	10·00	12½\
31	.	.	.	.	.	.	.	.	.	.	.	.
32	.	.	.	.	.	.	.	.	.	.	.	.
33	.	10½\	.	12 \	.	13 \	.	14½\	.	12 \	.	11 \
34	.	.	.	5½\	.	6 \	.	.	.	8½\	.	7 \
35	9·65	3 \	10·80	*v*	10·80	1½\	10·60	3 \	10·60	2 \	10·60	*v*
36	.	3½/	.	3 /	.	*v*	.	*v*	.	*v*	.	2½/
37	.	4 /	.	1½/	.	1½/	.	*v*	.	1 /	.	3½/
38	.	4½/	.	7 /	.	7 /	.	7 /	.	8 /	.	7 /
39	.	10 /	.	12 /	.	9½/	.	9 /	.	10 /	.	9 /
40	10·70	9½/	11·90	12½/	11·90	13 /	11·70	12½/	11·70	13 /	11·70	12 /

41	.	5½/	.	5½/	.	6 /	.	6 /	.	5½/	.	7 /
42	.	1½\	.	1 \	.	v	.	v	.	2 \	.	1 \
43	.	5 \	.	4 \	.	5 \	.	7 \	.	5 \	.	5 \
44	.	v	.	2½\	.	v	.	2 \	.	1 \	.	3 \
45	12·90	3 /	14·20	6 /	14·20	4½/	14·10	v	14·10	v	14·10	v
46	.	.	.	.	.	.	.	.	.	.	.	.
47	.	12 /	.	10 /	.	7½/	.	.	.	2 /	.	6 /
48	.	.	.	.	.	.	.	2½/	.	.	.	.
49	.	.	.	.	.	.	.	.	.	.	.	.
50	13·35	10 /	14·60	10½/	14·60	10 /	14·50	6½/	14·60	6 /	14·50	7 /
51	.	4½/	.	.	.	.	.	.	.	.	.	.
52	.	3½/	.	5½/	.	3 /	.	v	.	v	.	v
53	.	.	.	2½/	.	v	.	.	.	3 \	.	2 \
54	.	.	.	.	.	1 \	.	.	.	3½\	.	5½\
55	14·15	3½\	.	4 \	.	7½\	.	9 \	.	7 \	.	7 \
56	.	.	.	.	.	.	.	.	.	.	.	.
57	.	.	.	7 \	.	10 \	.	10½\	.	8½\	.	9 \
58	.	8½\	.	.	.	.	.	.	.	.	.	.
59	.	.	.	.	.	.	.	.	.	.	.	.
60	14·80	12 \	16·00	12 \	16·00	12½\	15·90	13 \	15·90	13 \	15·90	13 \
65		13 \	.	13 \	.	15½\	.	17½\		14½\		15 \
End	. .	. 14\	16·70	. 13 \	16·70	17½\	16·60	20 \	16·60	19 \	16·60	16½\

Table II (*continued*).

No. of ring	No. 7			No. 8			No. 9			No. 10			No. 11			No. 12		
	cms.			cms.			cms.			cms.			cms.			cms.		
10	1·30	v	v	1·20	2 /	1 /	1·10	4½/	v	1·30	3/	2 /	1·50	2/	1 /	1·30	v	2 /
11	.		1 /	.		v	.		1 \	.		1 \	.		2 \	.		1 \
12	.		2½/	.		1 \	.		2½\	.		3 \	.		3 \	.		2 \
13	.		2 \	.		2 \	.		3½\	.		2½\	.		3 \	.		1½\
14	.		2½\	.		3½\	.		3½\	.		2½\	.		3½\	.		4 \
15	2·70		4 \	2·70		3 \	2·70		2½\	2·70		2½\	2·80		1 \	2·70		2½\
16	.		v	.		v	.		v	.		v	.		2 /	.		1 /
17	.		2 /	.		3½/	.		3 /	.		3 /	.		4 /	.		3½/
18	.		5 /	.		4 /	.		3½/	.		3½/	.		6 /	.		8 /
19	.		7½/	.		5 /	.		v	.		3 /	.		7 /	.		5½/
20	5·10			5·00			5·00			5·00			5·00			5·00		
21	.		v	.		4 \	.		8 \	.		3 \	.		v	.		2 /
22	.		8 \	.		8½\	.		6 \	.		6 \	.		7 \	.		3½\
23	.		8½\	.		7 \	.		7 \	.		9½\	.		8 \	.		7 \
24	.		5 \	.		2 \	.		4 \	.		2½\	.		2½\	.		3½\
25	7·75		v	7·60		v	7·60		v	7·60		v	7·70		3½/	7·70		2½/
26	.		5 /	.		7 /	.		7 /	.		9 /	.		10 /	.		7 /
27	.		v	.		5 /	.		7 /	.		5 /	.		7½/	.		6 /
28	.		2 \	.		2 \	.		2½\	.		v	.		v	.		2 /
29	.		9½\	.		7 \	.		8 \	.		4 \	.		4½\	.		4 \
30	10·00		11½\	10·00		9½\	10·00		9 \	10·10		11 \	10·20		10 \	10·10		7 \
31	.		.	.		.	.		.	.		.	.		.	.		.
32	.		.	.		.	.		.	.		.	.		.	.		.
33	.		9 \	.		6 \	.		9 \	.		9 \	.		9½\	.		11 \
34	.		2½\	.		5 \	.		7 \	.		5½\	.		7 \	.		7 \
35	10·60		v	10·60		v	10·60		v	10·70		2 \	10·80		2½\	10·70		4 \
36	.		2½/	.		2 /	.		v	.		v	.		v	.		2 \
37	.		7 /	.		6 /	.		.	.		.	.		.	.		.
38	.		8½/	.		9½/	.		6 /	.		7 /	.		6½/	.		3½/
39	.		11 /	.		12 /	.		11 /	.		9 /	.		10 /	.		8½/
40	11·70		16 /	11·70		14 /	11·60		12½/	11·70		13 /	11·80		14½/	11·70		13½/

41	.	5½/	.	7 /	.	6½/	.	7½/	.	7 /	.	6½/
42	.	2 /	.	2 /	.	v	.	v	.	1 /	.	v
43	.	4 \	.	4½\	.	5 \	.	3 \	.	4½\	.	3½\
44	.	2½\	.	7 \	.	10 \	.	7½\	.	9½\	.	8 \
45	14·00	v	14·10	1½\	14·00	7 \	14·10	10 \	14·20	10½\	14·10	10 \
46	.	.	.	.	.	.	.	.	.	.	.	.
47	.	3 /	.	2 /	.	v	.	5 \	.	7½\	.	9 \
48	.	.	.	.	.	.	.	.	.	.	.	.
49	.	.	.	.	.	.	.	.	.	.	.	.
50	14·50	5½/	14·50	5 /	14·50	3 /	14·50	v	14·60	2 \	14·50	3½\
51	.	.	.	.	.	.	.	.	.	.	.	.
52	.	v	.	v	.	v	.	2½\	.	4 \	.	v
53	.	.	.	v	.	1½\	.	4 \	.	4½\	.	3 \
54	.	.	.	3½\	.	.	.	.	.	.	.	.
55	.	6½\	.	7 \	.	7½\	.	8½\	.	8 \	.	9½\
56	.	.	.	.	.	.	.	.	.	.	.	.
57	.	9 \	.	10 \	.	12 \	.	10½\	.	10 \	.	10½\
58	.	.	.	.	.	.	.	.	.	.	.	.
59	.	.	.	.	.	.	.	.	.	.	.	.
60	15·90	12 \	15·90	12 \	15·80	14½\	15·80	13 \	15·90	13½\	15·80	13 \
65	.	13½\	.	14 \	.	17 \	.	15 \	.	16½\	.	15 \
End	16·50	17½\	16·50	16 \	16·40	18½\	16·40	18½\	16·50	18½\	16·40	20 \

Table II (*continued*).

No. of ring	No. 13			No. 14			No. 15			No. 16			No. 18		
	cms.			cms.			cms.			cms.			cms.		
10	1·20	*v*	3 /	1·10	3/	3½/	1·10	2/	4 / .	1·00	*v*	4½/	·45	4/	2 /
11	.		*v*	.		2 /	.		3 /	.		1½/	·70		*v*
12	.		1 \	.		*v*	.		1 \	.		1½\	1·05		2 \
13	.		2½\	.		3½\	.		3 \	.		2½\	1·30		4 \
14	.		3½\	.		5½\	.		3½\	.		4½\	1·70		1 \
15	2·60		3 \	2·60		3 \	2·50		1½\	2·40		2½\	2·10		*v*
16	.		1 \	.		*v*	.		1½/	.		3 /	2·60		4 /
17	.		2½/	.		3 /	.		5 /	.		4 /	3·10		4 /
18	.		7½/	.		8½/	.		8 /	.		7 /	3·70		8½/
19	.		5 /	.		6 /	.		6½/	.		6 /	4·20		5½/
20	5·00			5·00			5·00			5·00					
21	.		3½/	.		1½/	.		1½/	.		*v*	4·50		*v*
22	.		3½\	.		3½\	.		4½\	.		6 \	5·10		6 \
23	.		8 \	.		7 \	.		8 \	.		7½\	5·75		8½\
24	.		4 \	.		3 \	.		5½\	.		4 \	6·25		2½\
25	7·70		*v*	7·60		2 /	7·60		*v*	7·50		3 /	7·00		3½/
26	.		7½/	.		7 /	.		5 /	.		6 /	7·40		9 /
27	.		6 /	.		7 /	.		6 /	.		6 /	8·05		7 /
28	.		2 /	.		3 /	.		1 /	.		2½/	8·70		3 /
29	.		4½\	.		2½\	.		4½\	.		3 \	9·30		2½\
30	10·10		9 \	10·10		5 \	10·10		7 \	10·10		9 \	9·75		5½\
31	.		.	.		.	.		.	.		.	9·80		.
32	.		.	.		.	.		.	.		.	9·90		.
33	.		13½\	.		10½\	.		9½\	.		11½\	10·00		11 \
34	.		9 \	.		7 \	.		7½\	.		7½\	10·10		.
35	10·70		6½\	10·60		4 \	10·70		4 \	10·60		6 \	10·20		4½\
36	.		3 \	.		1½\	.		2 \	.		4½\	10·40		3½\
37	.		.	.		.	.		.	.		.	10·50		*v*
38	.		2½/	.		4 /	.		2½/	.		1½/	10·60		3 /
39	.		6 /	.		8 /	.		6 /	.		6½/	10·90		4 /
40	11·70		11 /	11·60		12 /	11·70		10½/	11·60		10 /	11·20		9 /

41	.	5 /	.	6 /	.	4 /	.	4 /	11·80	3 /
42	.	1 /	.	v	.	v	.	v	12·50	v
43	.	4½ \	.	3½ \	.	4 \	.	4 \	13·00	5 \
44	.	7½ \	.	12 \	.	7½ \	.	8 \	13·45	9 \
45	14·10	13 \	14·00	12 \	14·10	11 \	14·00	12½ \	13·70	13 \
46	.	.	.	.	.	.	.	.	13·80	.
47	.	9 \	.	9 \	.	11½ \	.	12 \	13·90	17 \
48	.	.	.	.	.	.	.	.	14·00	.
49	.	.	.	.	.	.	.	.	14·10	.
50	14·50	4 \	14·50	3½ \	14·60	7 \	14·50	9½ \	14·20	13 \
51	.	.	.	.	.	.	.	.	.	.
52	.	v	.	v	.	2 \	.	6 \	.	.
53	.	1 \	.	1 /	.	1 \	.	3 \	.	9 \
54	.	.	.	.	.	.	.	.	.	.
55	.	8 \	.	4 \	.	v	.	2 \	14·70	5 \
56	.	.	.	.	.	.	.	.	.	.
57	.	.	.	6 \	.	6 \	.	4 \	.	1 \
58	.	10½ \	.	.	.	.	.	.	.	.
59	.	.	.	.	.	.	.	.	.	.
60	15·70	12½ \	15·70	9½ \	15·80	8 \	15·70	7½ \	15·10	v
65	.	17½ \	.	12 \	.	12½ \	.	10½ \	.	.
End	16·30	19 \	16·30	17 \	16·40	14½ \	16·30	13 \	15·75	6 \

causes, first, the numbering of the rings was done without comparison between the two series, and secondly, the fainter rings did not stand out so clearly in the sticks of the longitudinal series, with the result that a certain number of them escaped observation. However, the spacing of the rings and the phase of inclination shown by the grain clearly indicate that the 30th to 60th ring inclusive of the transverse series correspond with those numbered from 24 to 50 in the longitudinal series.

The diagram illustrating the longitudinal series (Fig. 4) shows that the curves which indicate the course of the grain in each stick agree together very closely as to form, a fact foreshadowed by the longitudinal parallel zones to be seen on the surface of a radial board, and demonstrate that in a radial plane the inclination of the grain alternates between left-handed and right-handed with the growth of the tree.

On reading off from Fig. 4 the position of each maximum inclination of the grain with reference to the rings, for the successive sticks of the longitudinal series it is seen that the position of each corresponding maximum inclination may remain the same through the series, for example, the one occurring between the 40th and 41st rings, or else it may vary within a range of two or three rings, or finally, as in the last two periods, the position of a maximum inclination of the grain may pass, on being traced through successive transverse levels, more to the exterior or *vice versa*, according to whether the series is examined from the one end or the other.

Thus in *Shorea robusta* it is apparent that though the periods are structurally continuous, their development at different transverse levels in the same radial plane is not necessarily simultaneous, though it usually is so.

From the curves for sticks 1 to 9 (Fig. 4) it is seen that some of the earlier periods do not retain their identity throughout the series; the period comprised between the 12th and 20th rings in stick 6 fades away in sticks 5 to 1, its place being taken by a fresh period. The board, unfortunately, was not long enough to extend beyond this transitional region to where the new period would be fully established.

In some of the other species this fading away of some periods and the increase in the prominence of others was of much more frequent occurrence, and constituted one of the chief causes of lack of correspondence shown by successive curves of a series whether transverse or longitudinal.

That the appearance of this transitional region is not due to errors in the determination of the inclination of the grain is proved by the

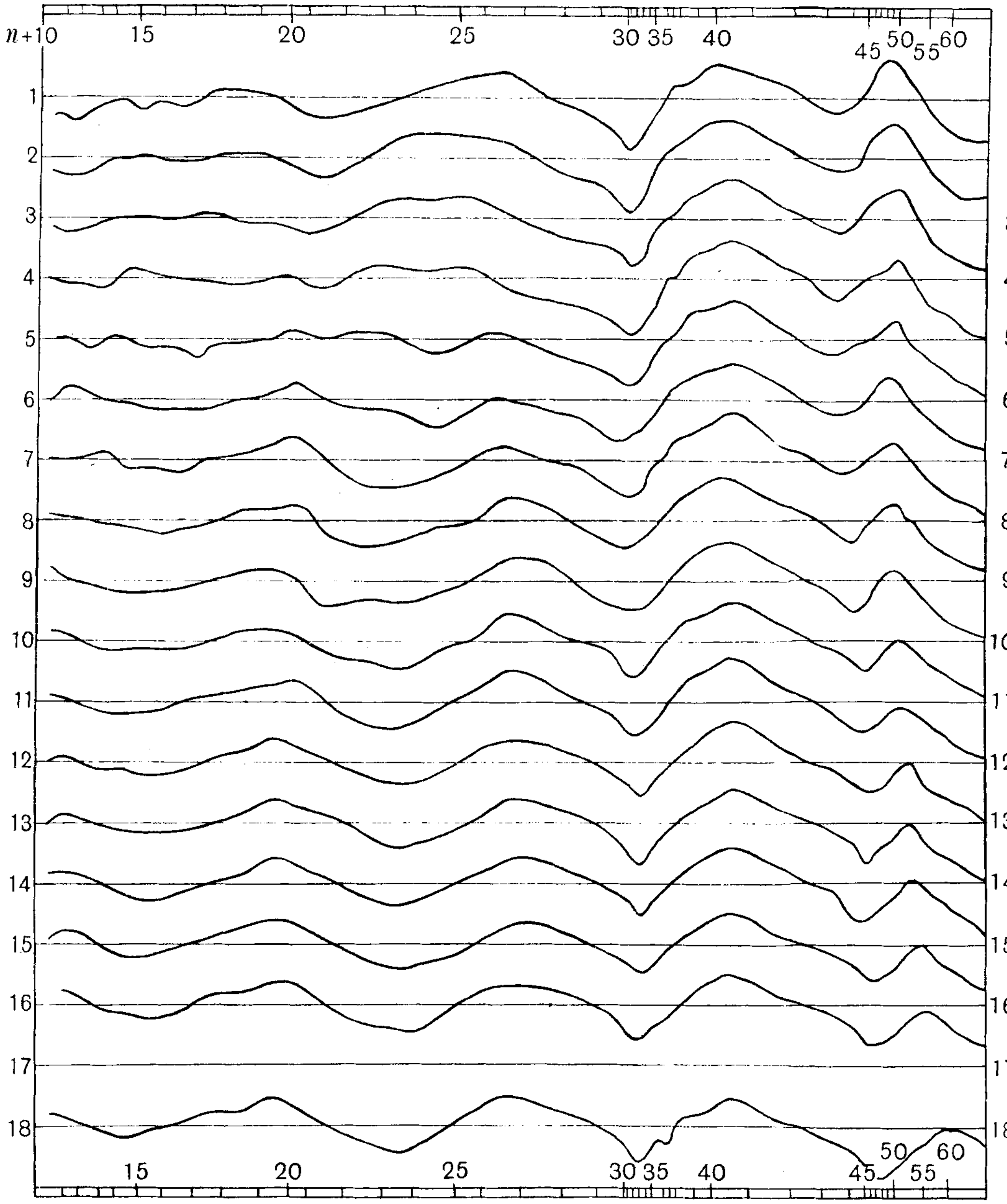

Fig. 4. *Shorea robusta.* Longitudinal series. A series of curves showing inclination of the grain along successive transverse sticks from a radial board an inch apart. Scale as in Fig. 3.

forms of the series of fractures obtained by the radial fracture of a series of sticks sawn transversely from the radial board adjacent to the one which supplied the data for the longitudinal series of curves (photograph 1).

It has already been pointed out that in a radial plane the positions of the periods are not rigidly fixed with reference to the growth-rings, and that there may be a considerable interval between the different transverse levels as to the time of the inception of a period. There is still a further inconstancy discoverable in the series. The actual inclination of the grain at different transverse levels in the same radial plane is not uniform at any ring, but varies in a very indefined manner from stick to stick, and coupled with this is a corresponding variation in the rate of change in the inclination of the grain.

The following example will serve to illustrate these variations. Between the 40th and 41st rings, Fig. 4, there is a maximum right-handed phase in all the sticks of the longitudinal series. Now the inclination of the grain at this point varies in a very irregular manner between 9 and 16 degrees, a range of variation far in excess of the probable error in measurement which was estimated at one degree.

Between the 42nd and 43rd ring the grain has become vertical, hence the rate of change in inclination of the grain could not have been uniform at the different transverse levels.

From the 43rd ring onwards the direction of the change in the inclination of the grain is still the same and reaches a maximum left-handed inclination of five degrees between the 43rd and 44th rings at the level of stick 1, after which the change in inclination of the grain becomes right-handed.

At other transverse levels, however, the grain is becoming still more left-handed, reaching a maximum of 13 degrees at the 45th ring in the 13th stick and of 17 degrees at the 48th ring of the 18th stick.

If the periodic changes in the inclination of the grain were simultaneous with periods of growth and the amplitude of the periods was constant, the grain would consist of a series of alternate left-handed and right-handed spirals (double spiral grain), but on account of the irregularities described above, the grain is composed of a series of superposed serpentine curves grading one into the other which, for short lengths of the trunk at least, tend to be arranged in the form of a double spiral.

The transverse series of curves (Fig. 3) shows a complete parallel correspondence in all points with the longitudinal series. At a transverse level the periodic changes in the inclination of the grain are continuous tangentially, the periods are not rigidly fixed with reference to the growth-rings, or in other words the periods are only approximately simultaneous, and finally the inclination of the grain at corresponding phases of a period vary from stick to stick. The result is that, though the inclination of the grain alternates between left-handed and right-handed when traced ring by ring from the centre to the exterior, around no ring is the inclination of the grain uniform while often it may change several times from left-handed to right-handed on being followed round. All these points can be followed in a careful scrutiny of the transverse series of curves.

The course of the grain having been determined there still remain some points of secondary importance to be investigated, namely the relations that exist between period length, amplitude, width of rings and age to tree.

In determining average period lengths and average amplitudes all doubtful cases were neglected in transitional regions where one set of periods was vanishing and another set appearing in its place.

The radial distance between two successive maximum right-handed or left-handed inclinations was used for obtaining average period lengths rather than the distance between succeeding vertical phases, since the former was likely to give more reliable figures as it may happen that a period may remain completely right-handed or left-handed in its inclination; for example, the period between the 47th and the last ring in the 16th stick of the longitudinal series which is wholly left-handed.

In Tables III and IV are given the period lengths in centimetres for the sticks of the longitudinal and transverse series respectively, and in addition is given the average period length for each stick and also the average length of the successive periods throughout the series.

The figures in Table III show that the greatest period length (4·15 cms.) in the longitudinal series is reached by the period comprised between the 15th and 23rd rings and that subsequently a decrease in the period length sets in. Correlated with the gradual shift of the last two periods towards the exterior (see Fig. 4) the average period length at the different levels in the longitudinal series shows a gradual increase from stick 6 to stick 18 (last column, Table III).

The measurements of the period lengths of the transverse series (Table IV) demonstrates that the average period length increases with age, as in the longitudinal series, to a maximum (4·35 cms.), after which it decreases. On comparing together the average period lengths of the different sticks it is seen that the period length varies directly with the radial rate of growth. That this should be so is to be inferred from the excentric growth of the tree and the tangential continuity of the periods in a transverse plane.

Table III.

Shorea robusta. Period lengths in centimetres in the longitudinal series.

Range of period in growth-rings	10–20	15–23	20–26	23–31	26–40	31–45	40–55	Average
	cms.	cms.	cms.	cms.	cms.	cms.	cms.	cms.
6th stick	3·75	4·40	3·40	3·00	3·90	3·65	2·65	3·54
7th ,,	3·20	3·70	3·45	4·05	3·90	3·50	2·65	3·50
8th ,,	4·25	3·35	3·70	4·35	3·50	3·80	2·80	3·68
9th ,,	—	3·85	4·35	4·40	3·50	3·70	2·75	3·76
10th ,,	3·65	4·20	4·15	3·85	3·75	3·85	2·75	3·79
11th ,,	4·15	4·35	3·60	4·05	3·65	3·80	2·85	3·79
12th ,,	3·55	4·25	4·05	4·00	3·60	3·80	2·90	3·74
13th ,,	3·55	4·10	3·95	4·00	3·65	3·70	2·90	3·70
14th ,,	3·40	4·10	4·05	4·05	3·60	3·60	3·05	3·70
15th ,,	3·45	4·30	4·15	4·05	3·40	3·90	3·20	3·78
16th ,,	3·80	4·35	3·85	3·70	3·50	3·90	3·30	3·77
17th ,,	—	—	—	—	—	—	—	—
18th ,,	—	4·50	3·85	2·95	3·70	4·05	3·70	3·96
Average	3·68	4·15	3·88	3·96	3·64	3·77	2·96	3·73
No of rings per period	8	7	7	13	13	13	23	—

Table IV.

Shorea robusta. Period lengths in centimetres in the transverse series.

	Range of period in growth-rings	25–35	30–44	35–53	44–63	53-end	Average
		cms.	cms.	cms.	cms.	cms.	cms.
Radial sticks from the disc	A	4·35	4·70	5·50	4·35	3·10	4·40
	A 1	4·80	4·60	5·25	4·80	3·70	4·64
	A 4	4·10	5·55	3·65	3·40	4·50	4·24
	A 7	3·05	3·90	3·85	4·50	5·00	4·06
	B	3·35	4·10	4·15	4·50	4·20	4·06
	B 1	3·57	4·11	4·58	4·30	3·45	3·99
	B 2	3·41	4·40	5·50	3·80	2·30	3·88
	B 3	3·50	5·17	5·45	4·00	2·20	4·06
	C	2·56	4·55	4·40	3·80	3·35	3·73
	D	2·40	2·20	2·45	3·40	3·70	2·83
	D 3	2·30	2·45	2·80	4·10	3·35	3·00
	Average	3·40	4·15	4·35	4·10	3·55	3·90
	No. of rings per period	13	15	18	20	32	—

The magnitude in degrees of the successive right-handed and left-handed swings in the inclination of the grain are given for the longitudinal and transverse series in Tables V and VI respectively. The

Table V. *Shorea robusta.* Table showing the amount in degrees of the successive right- and left-handed swings of the grain for the longitudinal series.

Change in direction of grain and the rings between which included	Left 12th-15th	Right 15th-20th	Left 20th-23rd	Right 23rd-26th	Left 26th-31st	Right 31st-40th	Left 40th-45th	Right 45th-55th	Left 55th-end	Average
1st stick	—	—	9°	15°	26°	28°	16°	17°	27°	—
2nd ,,	—	—	7	13	25	30	17	15	24	
3rd ,,	—	—	6	14	22	29	18	15	27	—
4th ,,	—	—	5	7	22	31	20	13	27	—
5th ,,	—	—	—	—	17	28	18	11	26	—
6th ,,	7°	9°	15	10	14	25	17	12	23	15°
7th ,,	7	11	16	14	17	28	20	10	25	16
8th ,,	7	9	13	16	17	23	20	12	22	15
9th ,,	11	8	12	16	17	22	23	13	22	16
10th ,,	6	7	13	18	20	24	23	10	20	16
11th ,,	6	11	15	19	21	25	25	8	16	16
12th ,,	6	12	15	15	18	25	24	10	22	16
13th ,,	6	10	16	16	22	25	24	13	20	17
14th ,,	9	15	16	16	19	22	25	14	19	17
15th ,,	8	12	16	15	16	20	22	12	17	15
16th ,,	10	13	16	14	17	21	23	11	—	16
18th ,,	8	13	18	19	21	20	26	17	—	18
Average swing	8	11	13	15	19	25	20	13	22	16

Table VI. *Shorea robusta.* Table showing the amount in degrees of the successive right- and left-handed swings of the grain for the transverse series.

	Change in direction of grain and the rings between which included	Left 25th-30th	Right 30th-35th	Left 35th-44th	Right 44th-53rd	Left 53rd-63rd	Right 63rd-80th	Average	Average period length in cms.
Radial sticks from the disc	A	19°	23°	23½°	25°	30½°	23°	24°	4·40
	A 1	13	16	26	32	35	22	24	4·64
	A 4	14	17½	30	35	31	13	25	4·24
	A 7	7	18	27	23	20	20	19	4·06
	B	11	23	31	26	21	23	23	4·06
	B 1	14	24	33	27	23	25	24	3·99
	B 2	12	23	32	26	21	20	22	3·88
	B 3	7	18	28	26	23	17	20	4·06
	C	16	18	32	32	24	18	23	3·73
	D	17	17	21	16	20	18	18	2·83
	D 3	21	16	22	24	24	20	21	3·00
Average swing		14	19	28	27	25	20	22	3·90

average (Table V) amplitude remains approximately constant at the successive transverse levels in the longitudinal series, its value ranging between 15 and 18 degrees, but on the other hand the average value of the successive swings increases with age up to a maximum of 25 degrees which is followed by a slight subsequent decrease in value. The figures of Table VI show that the same is true of the transverse series. Although both period length and amplitude reach their maximum value at about the same time, yet the two do not appear to be very closely correlated, for the subsequent decrease in the period length is so much greater than the decrease in the amplitude that the ratio of period length to amplitude steadily decreases with age except for the last period of the transverse series which shows a slight decrease.

On comparing together the average period length and the average amplitude, there are indications that in the transverse series the longer periods are correlated with bigger amplitudes, but no such correlation is apparent in the longitudinal series.

The correlation of period length and amplitude with width of ring is much more indefinite and is only recognisable in so far as all three tend to increase with age up to a maximum which is followed by a greater or smaller subsequent decrease.

CHLOROXYLON SWIETENIA.

The curves of the longitudinal and transverse series are given in Figs. 5 and 6 respectively, but the data from which they have been constructed are not printed here.

The numbering of the rings in the two series is practically identical as the several zones of narrow rings afforded reliable points for comparison.

Due to the uniformity in the rate of growth, the proportional width of the rings remained the same along the different radii of the transverse disc, so the ring widths were only measured along three of the sticks. In the longitudinal series the ring widths were fully measured along one stick from the middle of the series.

An examination of the longitudinal and transverse series of curves shows that the course of the grain in *Chloroxylon Swietenia* is very similar to what it is in *Shorea robusta.* The periodic changes in the inclination of the grain are continuous both longitudinally in a radial plane and tangentially at a transverse level. The inclination of the grain at corresponding points of a period does not remain the same in adjacent sticks of the transverse series or at the different transverse levels in the longitudinal series, a striking instance occurring at the 100th ring of the

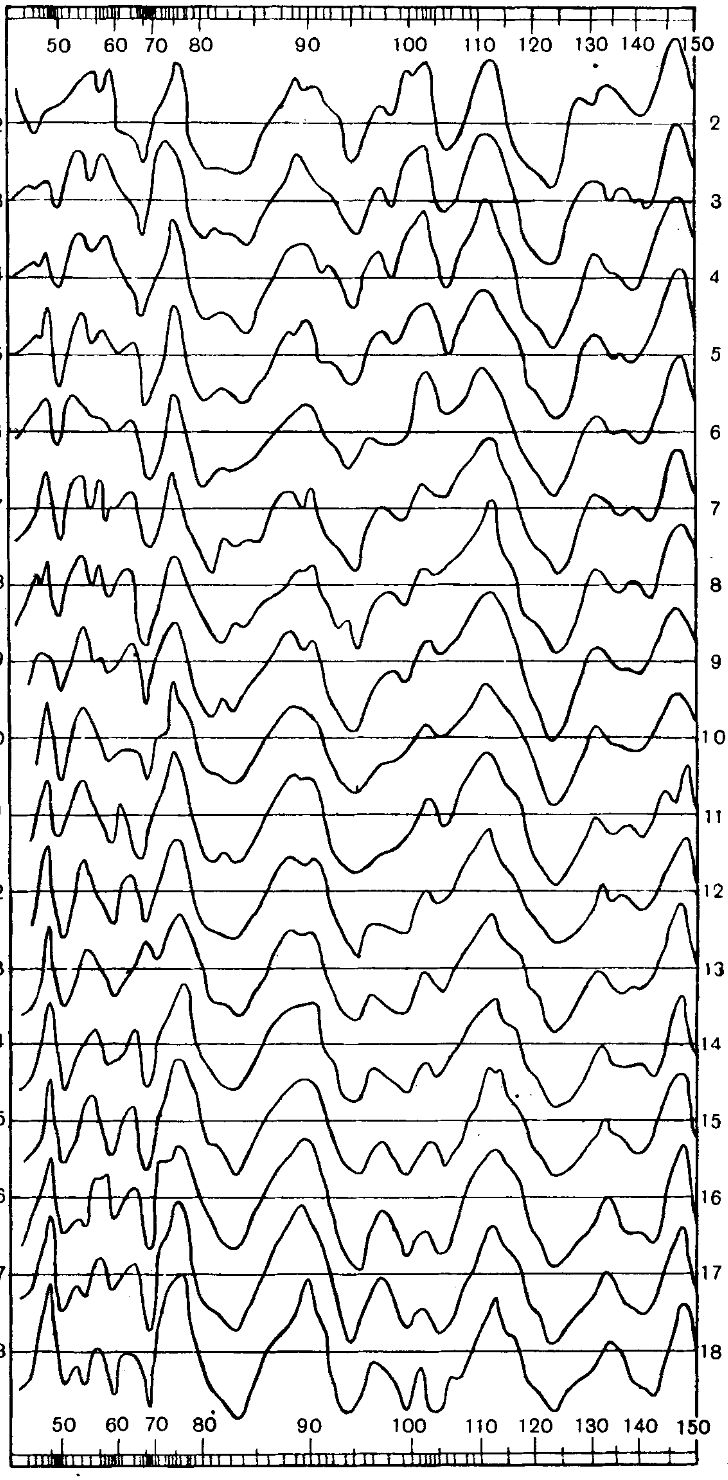

Fig. 5. *Chloroxylon Swietenia*. Longitudinal series. Scale as in Fig. 3.

longitudinal series. The consequence is that the rate of change in the inclination of the grain will not be uniform at any moment, resulting in the grain being composed of a series of superimposed serpentine curves.

Although the general course of the grain in *Chloroxylon Swietenia*

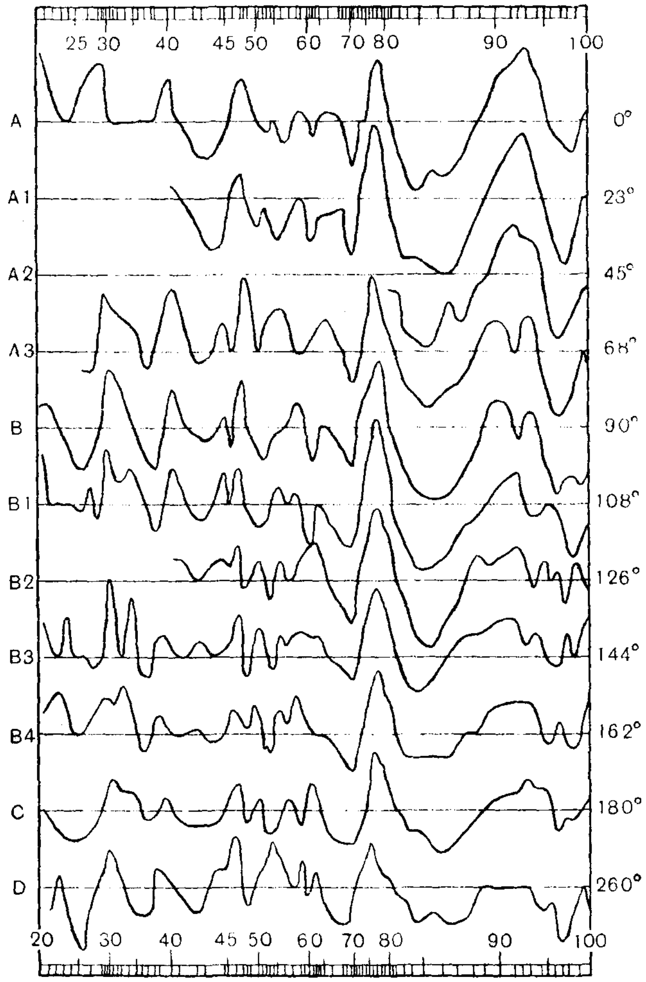

Fig. 6. *Chloroxylon Swietenia.* **Transverse series. Scale as in Fig. 3.**

and *Shorea robusta* agree very closely together, yet, as might be expected, there are numerous minor differences between the two species.

The length of the period which in *Shorea robusta* ranges between 3 and 4 cms. has an average value of a little less than 1 cm. in *Chloroxylon*

Swietenia. The amplitude is greater in *Chloroxylon*, reaching a maximum of 40 degrees as compared with 30 degrees in *Shorea*.

The net result of a shorter period and a bigger amplitude is that the rate of change in the inclination of the grain will be more rapid, and when this is combined with narrow growth-rings errors in the practical work of investigation will be much more frequent than under the opposite conditions of broad rings and a slow rate of change in the inclination of the grain.

In spite of these disadvantages in *Chloroxylon Swietenia* the Plate, fig. II, of the series of curved fractures obtained by the method of radial splitting, shows that the errors from this source are not so serious as might be expected.

On comparing the position of the periods with reference to the growth-rings in the sticks of the two series it is seen that the periods in *Chloroxylon* are much more closely connected with the growth-rings and show no tendency to cut across periods of growth as in *Shorea robusta*.

Exceptions to this contemporaneity of the periods are due to the somewhat frequent appearance of subsidiary or union periods which retain their identity through a series for short distances only, the period appearing at the 44th ring in sticks A3, B, B1 and B2 if the transverse series is a case in point. Many more of these subsidiary periods can be recognised in the curves of the transverse and longitudinal series.

On account of the frequent appearance of these subsidiary periods it was difficult to obtain data which could be relied on to the relation between period length, amplitude, width of ring and age.

If the 15th stick of the longitudinal series is taken as representing the average condition of the grain for the series it is seen that long periods occur equally where the rings are broad as where they are narrow. No gradual increase in period length, with age, up to a maximum followed by a subsequent decrease is seen as in *Shorea robusta*.

On the other hand it was found on calculating the average that the biggest amplitudes were always correlated with the longest periods.

GMELINA ARBOREA.

The examination of *Gmelina arborea* showed that the grain possesses the same serpentine character that is characteristic of the two species already described.

The method of radial splitting as applied to a portion of the disc showed that the periods are tangentially continuous at a transverse level (see Plate, III). The series of curves which were obtained from the

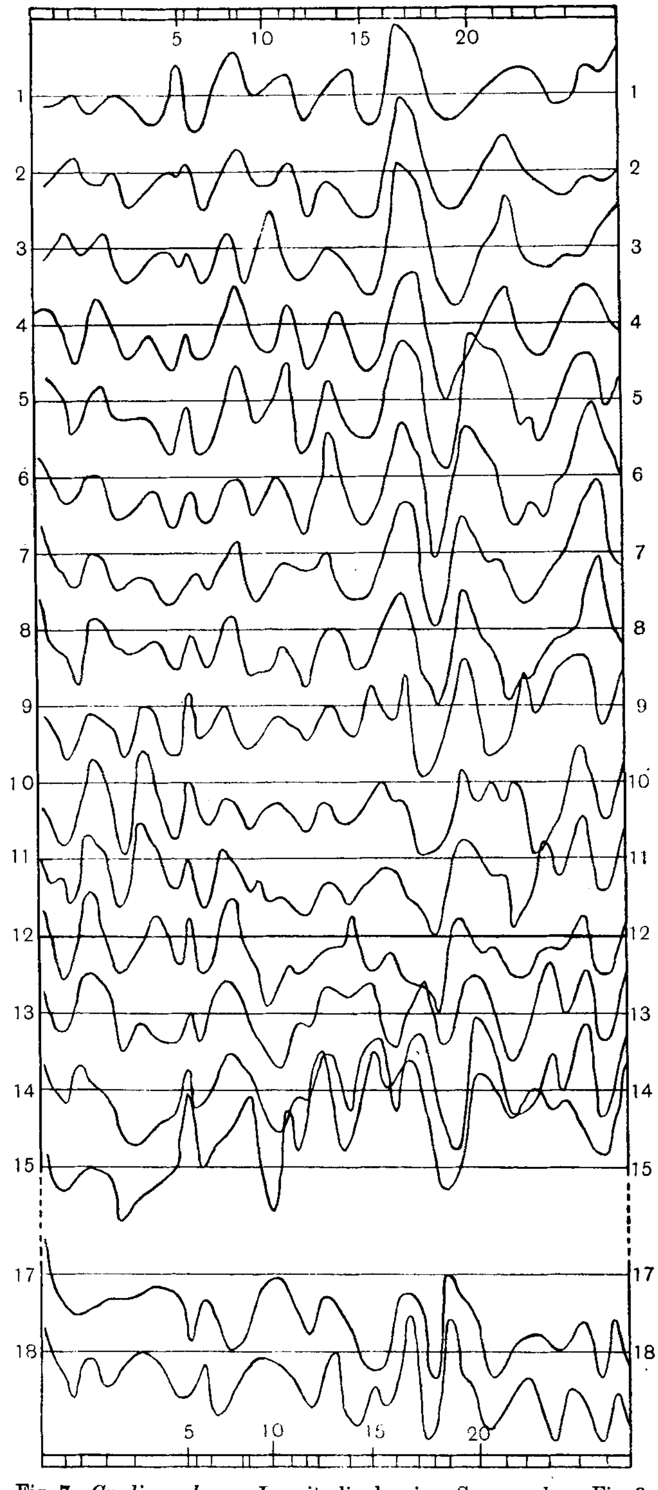

Fig. 7. *Gmelina arborea.* Longitudinal series. Same scale as Fig. 3.

examination of the sticks of the transverse series, however, showed very poor correspondence. This lack in correspondence was due to inaccuracies attributable to the great excentricity of the trunk, the short period

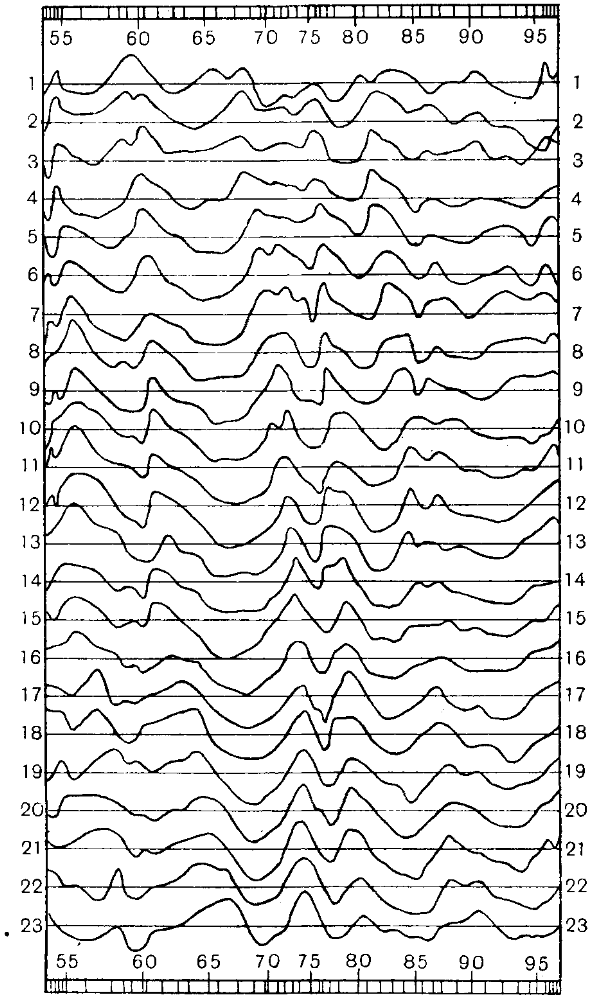

Fig. 8. *Xylia dolabriformis*. Longitudinal series. Same scale as Fig. 3.

length (0·70 cms.) and the frequency with which adjacent rings coalesced for comparatively long tangential distances.

The character of the longitudinal series of curves (Fig. 7) differs in no essential from those of *Shorea* and *Chloroxylon*. The periods are continuous in a longitudinal direction; they are not accurately simultaneous; and the rate of change in inclination of the grain is not the same at different transverse levels in the same radial plane at the same moment resulting in the prominence of a period varying through the series.

In estimating the average period lengths and amplitudes in the longitudinal series, it was only possible to arrive at approximate values. The figures that were obtained showed that the period length and amplitude had their maximum value near the exterior but no gradual increase in value with age was shown as in *Shorea robusta*.

The disturbance caused by a small branch trace is shown very clearly in sticks 15, 16 and 17 of the longitudinal series. The branch trace passed horizontally outwards at the side of stick 16. The curves of sticks 15 and 17 show that as in straight-grained wood the grain as a whole curves round the knot retaining, however, its cross-grained character.

XYLIA DOLABRIFORMIS.

As the disc had already been used for a general investigation of the course of the grain, it was only possible to examine the course of the grain in detail in the plane of a radial board.

The data for the sticks of the longitudinal series are not printed here but the curves constructed from them are given in Fig. 8.

Taking the results obtained from the investigation of the disc in conjunction with the longitudinal series, it is clear that, as in the other species examined, the inclination of the grain as a whole alternates with growth between right-handed and left-handed, and also, as in the other species, the absence of complete contemporaneity of the periods at the various transverse levels and differences in the rate of change in the inclination of the grain at any moment, result in the grain consisting of a series of superposed serpentine curves.

HARDWICKIA BINATA.

In the transverse series the rings were counted accurately only as far as the 27th ring, after which only the more prominent rings lettered *V*, *W*, *X* and *Y* were traced round. In each stick the space between each two of these prominent rings was divided up into eight pseudo-growth rings of equal width. This procedure was adopted as the disc had not been smoothed sufficiently for tracing the fainter rings.

In the longitudinal series on the other hand the rings could be counted with precision from the centre to the exterior. As the board did not contain the pith the numbering of the rings in the two series does not correspond but as far as can be judged the 20th ring of the transverse and the 25th ring or the 26th ring of the longitudinal correspond.

An examination of the longitudinal and transverse series (Figs. 9

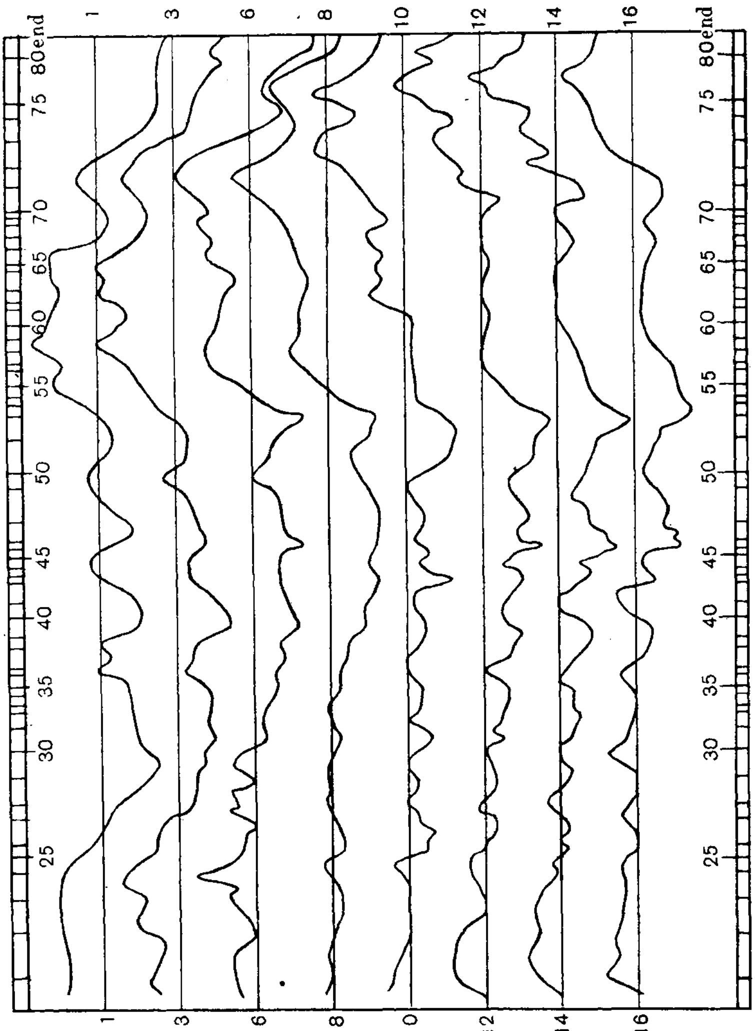

Fig. 9. *Hardwickia binata*. Longitudinal series. Same scale as Fig. 3.

and 10) on the lines adopted for *Shorea robusta* and the other species shows that the serpentine grain of *Hardwickia binata* follows the same general rules as in the species already examined.

In some respects the character of the grain differs from the typical form of serpentine cross-grain as shown in *Shorea robusta* and *Chloroxylon Swietenia*. The longitudinal and parallel zones are not readily distin-

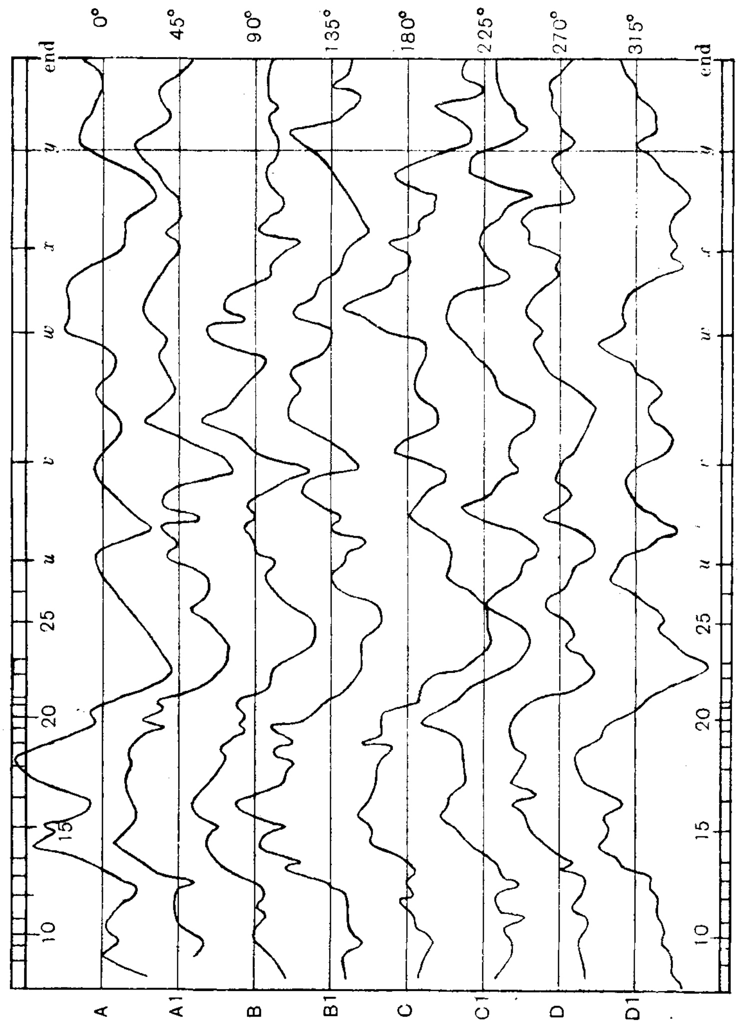

Fig. 10. *Hardwickia binata*. Transverse series. Same scale as Fig. 3.

guishable on a radial board which is due partly to the shortness of the period length and the comparatively small amplitude and partly to periods combining to form compound periods of big extent: stick 3 of the longitudinal series supplying a good example.

Although, as the transverse series shows, these compound periods persist completely round at a transverse level, it seems that they are of only limited longitudinal extent.

CALOPHYLLUM[1] SP. POON.

For the material of this species I am indebted to Professor Groom for permission to saw a transverse section off each end of a six-foot beam of Poon wood, 10 inches by 3 inches in section, the longest side of the section being in a radial plane.

The rings were counted on both sections and to ensure identity in numbering every fifth ring was traced from end to end on the radial surface of the beam. The ring nearest the centre was numbered 1 but it was impossible to say how far it might have been from the centre, but the shape of the rings indicated that the beam had been sawn from near the outside of a very large trunk.

The numbering of the rings on the two sections only approximately correspond as difficulty was encountered in tracing the rings along the beam due to the rings frequently fading away, although in many cases they reappeared after a longer or shorter distance.

In Table VII are given the data derived from a radial stick sawn from each transverse section and the corresponding curves are shown in Fig. 11. The rings were plotted natural width and not to a scale of 2 to 1 as for the other species.

The striking feature of Poon wood is the great length of the period ($8\frac{1}{2}$ cms.), being a little more than twice that of *Shorea robusta*. In another specimen of Poon, and probably of the same species, having the same number, four, of rings per centimetre, the period length was 6 cms. This fact suggests that a study of double cross-grain with reference to soil and climate would yield interesting results.

If the rings are used as an index of contemporaneity, though this is somewhat open to doubt for Poon wood, it is seen that the periodic changes in the inclination of the grain are practically simultaneous through a length of six feet, contrasting with the comparatively big shift in the position of some of the periods of the longitudinal series of *Shorea robusta* and *Xylia dolabriformis*.

Judging from the contemporaneity of the periods and the slight variation in their amplitude at the two levels it is to be inferred that the grain in Poon is a true double spiral.

[1] The specific identity of the wood examined was doubtful, though it bore the name of Poon, which belongs to *Calophyllum tomentosum*.

Table VII. *Calophyllum* sp. Spacing of rings in cms. and inclination of grain in degrees along two radial sticks in same radial plane and six feet apart.

No. of ring	Bottom stick		Top stick		No. of ring	Bottom stick		Top stick	
	cms.		cms.			cms.		cms.	
n+0	0	4½/	0	—	n+46	13·15	3 \	13·00	5 /
n+1	·01	7 /	·20	v	47	13·40	2½\	13·30	6 /
n+2	·35	5 /	·30	4½\	48	13·80	2½/	13·55	8 /
3	·50	3½/	·60	6½\	49	14·00	5 /	13·85	8½/
4	·70	1 /	·85	v	50	14·20	7½/	14·00	11½/
5	1·10	2 \	1·10	½\	51	14·50	7½/	14·20	13 /
6	1·40	3½\	1·40	2 \	52	14·75	6½/	14·40	12½/
7	1·60	5 \	1·65	4 \	53	15·00	6½/	14·60	10 /
8	1·80	5 \	1·75	3 \	54	15·25	9 /	14·70	8½/
9	2·10	6 \	1·90	6 \	55	15·50	10 /	14·90	8 /
10	2·35	8½\	2·20	8 \	56	15·65	6½/	15·05	4½/
11	2·70	10 \	2·45	9 \	57	15·90	2 /	15·25	4 /
12	3·00	7 \	2·70	7½\	58	16·10	1 \	15·50	3 /
13	3·40	9 \	2·95	6 \	59	16·25	1½\	15·70	2 /
14	3·70	9 \	3·20	6 \	60	16·50	2½\	15·90	3 \
15	4·20	7 \	3·45	5 \	61	16·85	4 \	16·00	2½\
16	4·70	4 \	3·90	v	62	17·00	4½\	16·20	4½\
17	5·10	2 \	4·15	6½/	63	17·10	7 \	16·40	6½\
18	5·30	v	4·30	7½/	64	17·25	5½\	16·70	6 \
19	5·60	1½/	4·50	7½/	65	17·45	5½\	16·90	4½\
20	5·90	1 /	4·65	9½/	66	17·70	7½\	17·05	7½\
21	6·30	2½/	5·00	11½/	67	17·90	8½\	17·25	9 \
22	6·60	6 /	5·40	13½/	68	18·15	10½\	17·45	11 \
23	6·90	11 /	5·80	11 /	69	18·40	11 \	17·85	14½\
24	7·25	11½/	6·30	8½/	70	18·50	9½\	18·10	11 \
25	7·65	10 /	6·70	5 /	71	18·75	11½\	18·30	11 \
26	8·00	9 /	7·20	3 /	72	19·00	13½\	18·55	9½\
27	8·30	7 /	7·50	v	73	19·25	14 \	18·70	7 \
28	8·60	5 /	7·85	2 \	74	19·50	15½\	18·85	5 \
29	8·90	1½/	8·15	3 \	75	19·80	15 \	19·05	3½\
30	9·15	v	8·45	4 \	76	20·00	11 \	19·25	1½\
31	9·45	2 \	8·75	5 \	77	20·20	7 \	19·55	3 /
32	9·65	3 \	9·00	7 \	78	20·40	7 \	19·80	3½/
33	9·85	2 \	9·30	9 \	79	20·65	4 \	19·95	3 /
34	10·10	2½\	9·60	7½\	80	20·85	3 \	20·10	4 /
35	10·35	6½\	9·80	13 \	81			20·25	3 /
36	10·70	6 \	10·00	11 \	82			20·40	4½/
37	10·90	5 \	10·30	11 \	83			20·70	5 /
38	11·10	8½\	10·60	9½\	84			20·90	8½/
39	11·30	10 \	10·90	8 \	85			21·10	7 /
40	11·55	10 \	11·20	6½\	86			21·30	9 /
41	11·70	9 \	11·60	—	87			21·45	12½/
42	11·85	8½\	11·80	3 \	88			21·65	14 /
43	12·20	8½\	12·20	2 \	89			21·85	9 /
44	12·60	6 \	12·50	2 /	n+90			22·05	9½/
45	12·90	6 \	12·80	4 /					

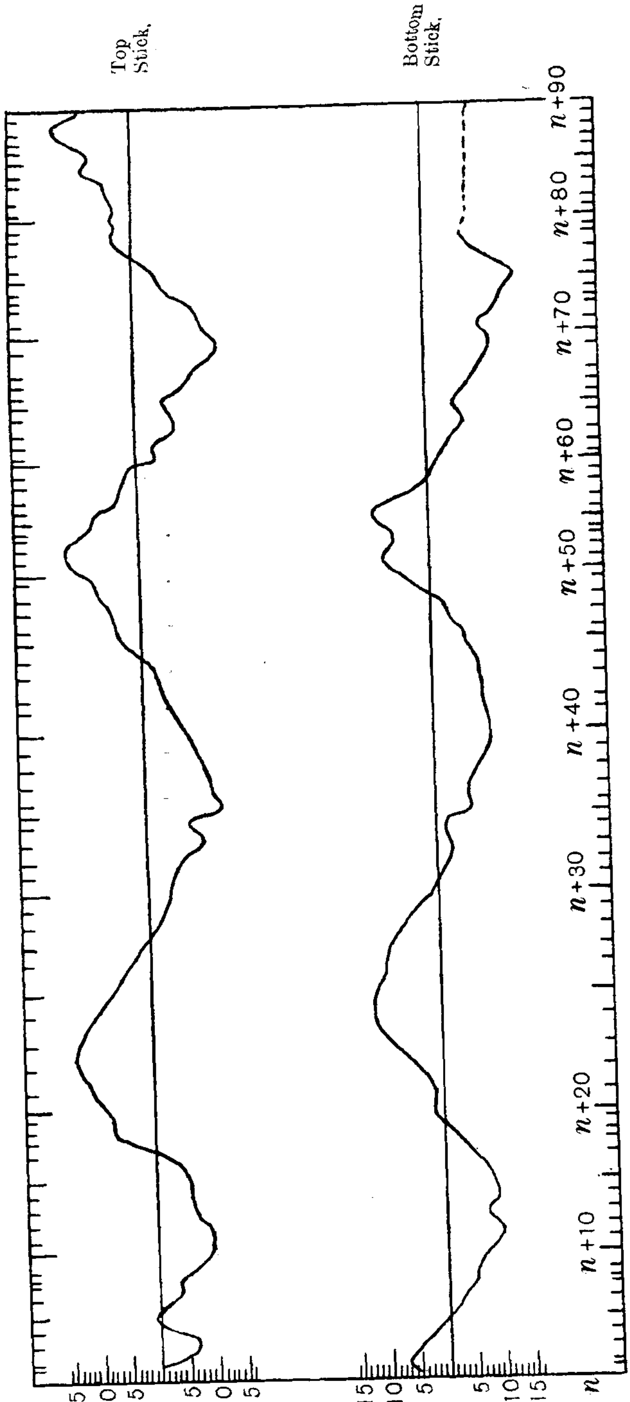

Fig. 11. *Calophyllum* sp. Two curves showing inclination of the grain in two radial sticks six feet apart and in the same radial plane. Rings numbered from "n" to "$n+90$." Scale: rings plotted natural width and angles of inclination 1 mm. to 1 degree.

Remaining Species.

All the remaining species were examined by the method of radial fracture alone. In no case was any type of cross-grain discovered which did not agree in essentials with that which is characteristic of the species examined in detail.

Even in the straight-grained *Albizzia procera,* slight variations in the grain, too small to be investigated by the detailed method, could be detected which conformed to the same general laws which applied to *Shorea robusta,* etc.

In Fig. IV, of the Plate, are shown the fractures obtained in a portion of the transverse disc of *Holoptelea integrifolia* and, in Fig. V, the fractures in the longitudinal series of sticks.

General Considerations.

During the course of this investigation several points stood out with sufficient prominence to merit a short discussion anent their probable significance.

The wide distribution of double cross-grain and the uniformity of its character among trees of the most diverse natural orders suggest that it is the expression of some peculiarity common to a large circle of affinity in the vegetable kingdom.

The long series of intermediate forms between straight grain and the full expression of double cross-grain reached by the serpentine cross-grain of *Shorea robusta* and the probable double spiral of *Calophyllum,* and the variation in its development among the members of the same family (see Fig. 1), suggest that there is something, whether of internal or external nature, that inhibits or enhances the expression of double cross-grain, but for the formation of a correct judgment on this point, research is necessary on the influence of local conditions of soil and climate on the development of this type of grain.

There may be, possibly, some correlation between a hot climate and the prevalence of this type of grain, but this can only remain a supposition until temperate climate trees and a larger number of trees from hot climates have been examined from this point of view.

In the attempt to place double cross-grain in proper perspective with reference to other phenomena shown by living objects. a close similarity was found to exist between the changes in the inclination of the grain and the phenomenon of periodicity.

Periodic phenomena among living organisms can be classed under two heads. Under "Induced Periodicity" are included all those cases which show a more or less direct correlation with the rhythm in external conditions; for instance diurnal and seasonal changes are reflected in the periodicity shown by growth and leaf-fall.

Under "Innate Periodicity" are included all those cases in which no correlation can be demonstrated to exist between the rhythm shown by a living object and the rhythm in external conditions, examples being the alternating streaming movements of the protoplasm of Myxomycetes and the leaf-fall of trees of tropical climates which are characterised by, at the most, only feebly marked seasonal changes (Schimper (4)).

It is under this latter head that the phenomenon of double cross-grain naturally falls for, relying on the evidence of the rings, no correlation could be established between seasonal changes and the period of the grain.

Some interesting analogies are shown between double cross-grain and the leaf-fall of trees native of regions showing absence of seasonal changes (see Schimper). Corresponding with the full development of double cross-grain are those trees which completely shed their foliage at regular intervals varying from two to twelve months, irrespective of the time of year. Trees in which the periodicity of the cross-grain is synchronous only within narrow limits in the trunk are paralleled by those trees which, considered as a whole, are evergreen, but in which the individual twigs are alternately bare and clothed with foliage.

If this type of grain is the expression of some periodicity in the life processes, it is to be expected that other periodic variations, synchronous with the variations in the inclination of the grain should be found. With this object in view the fibre lengths in *Chloroxylon Swietenia* and in *Calophyllum* were determined along a stick at points where the grain was straight and where it was inclined at a maximum.

The figures which are shown in Table VIII are very suggestive, but the inference that there is a correlation between a longer fibre length and inclined grain has no very sound statistical basis for 500 is not a large enough basis for determining a mean where the deviation from the mean is so large in comparison to the difference in the mean fibre length of the successive samples.

Since very little is known of the mechanical effects due to the increase in length of the young fibres it is impossible to say whether the changes in the inclination of the grain might be directly attributable to a variation in fibre length such as is indicated above. The impression obtained, however, during the course of the investigation was that the changes in the inclination of the grain were due to changes in the orientation of the cambial cells and that the fibres elongated in the direction in which they were laid down when cut off from the cambial cells and that it was not exigencies of spaces that caused their deviation from the straight.

Table VIII. *Chloroxylon Swietenia.* Variation in the mean fibre length with inclination of the grain.

Ring and direction of inclination of grain	76th/	78th v	83rd\	85th v	88th/	92nd v	94th\	97th v	99th/
Basis (number of fibres measured)	502	400	500	496	500	600	288	507	530
Mean fibre length in mms. ...	1·050	1·02	·965	·982	·990	·954	1·040	·968	1·030
Mean deviation from mean fibre length in mms. ...	·125	·151	·123	·145	·140	·159	·160	·137	·110
% of fibres within the mean deviation	54	54	53	60	57	58	53	58	57

	108th v	112th/	118th v	124th\	132nd v	140th\	144th v	148th/	150th v
Basis (number of fibres measured)	500	515	424	330	314	468	459	382	481
Mean fibre length in mms. ...	·935	·875	·845	·900	·817	·844	·826	·854	·847
Mean deviation from mean fibre length in mms. ...	·107	·102	·109	·110	·100	·105	·82	·102	·110
% of fibres within the mean deviation	59	56	56	57	57	57	57	57	56

Table IX. *Calophyllum* sp. Variation in the mean fibre length.

Ring and direction of inclination of grain	$(n+3)$th \	$(n+10)$th v	$(n+17)$th /	$(n+25)$th v	$(n+34)$th \	$(n+37)$th v
Basis (number of fibres measured)	100	100	100	100	100	100
Mean fibre length in mms.	1·160	1·080	1·160	1·020	1·140	1·110
Max. fibre length in mms.	1·710	1·460	1·660	1·450	1·610	1·800
Min. fibre length in mms.	·780	·760	·810	·680	·840	·790

With regard to its commercial aspect the economic value of a study of cross-grain lies in its application in the practice of seasoning wood. The main problems in the seasoning of wood centre round the differences in the rate of loss of moisture and in shrinkage during drying in radial, tangential and longitudinal directions, hence knowledge of the degree of cross-grain shown by different woods is essential if the economic mean between care expended and time involved is to be gauged.

SUMMARY.

1. The character of the double cross-grain of the different Indian woods examined is remarkably uniform and conforms to the following generalisations:

(*a*) The grain alternates between right-handed and left-handed in inclination during the growth of the tree, these changes in the inclination being in general synchronous in the trunk at least over lengths of two feet.

(*b*) That the grain does not consist of alternate right- and left-handed spirals is due to the rate of change in inclination of the grain not being uniform at any moment during the growth of the tree either in a tangential or longitudinal direction with the result that the double spiral character is obscured, giving place to a serpentine configuration.

2. Transitional types of grain between straight grain and the full development of double cross-grain are due to variations in the—

(*a*) regularity shown in the length of the successive periods,
(*b*) regularity in the amplitude of the successive periods,
(*c*) stability of the periods over longer or shorter tangential and longitudinal distances.

3. No correlation could be inferred, from the data available, as existing between seasonal changes or periods of growth and the periodicity shown in the inclination of the grain.

There were indications, however, that both period length and amplitude increased with age up to a maximum, and that a long period length was correlated with a big amplitude. Period length responds to the general rate of growth for, in trees of excentric growth, the period length was shortest along the smallest radius.

4. Fibre measurements in *Calophyllum* sp. and *Chloroxylon Swietenia* suggest that a longer fibre length is correlated with inclined grain and a shorter fibre length with straight grain.

5. The character and widespread occurrence of double cross-grain indicate that it is the expression of some periodic phenomenon whether of internal or external nature, but it remains to be seen to what extent a more extended investigation will bring it into line with other periodic phenomena shown by living organisms.

This research was carried out in the Woods and Fibres Department of the Imperial College of Science and Technology, South Kensington, while the author was in receipt of a studentship from the Department of Scientific and Industrial Research.

In conclusion I wish to record my thanks to Professor Percy Groom for suggesting this investigation, providing the material and for help throughout the progress of the work.

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DESCRIPTION OF PLATE XIII

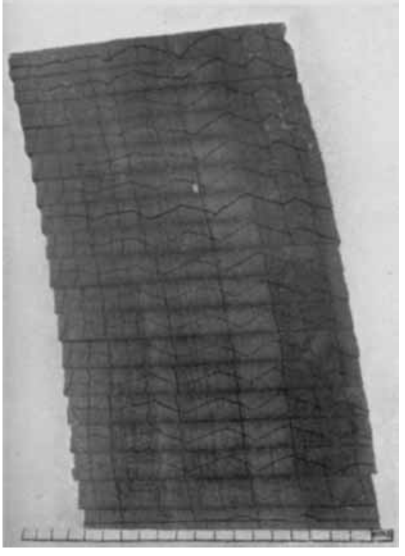
I. *Shorea robusta.* The series of fractures obtained by radially splitting sticks sawn transversely an inch broad, from an 18 inch radial board. Several of the more prominent rings inked over.

II. *Chloroxylon Swietenia.* Prepared as in I.

III. *Gmelina arborea.* Radial fractures obtained in a portion of the transverse disc. Several rings inked in.

IV. *Holoptelea integrifolia.* Radial fractures in a portion of the transverse disc.

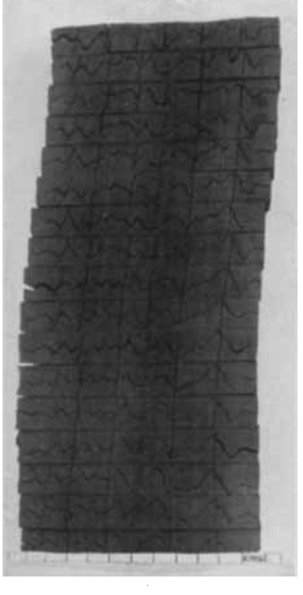
V. *Holoptelea integrifolia.* Longitudinal series of fractures prepared as in I.



I

III

IV



II

V